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STEAM REFORMING OF METHYL FUEL — PHASE I

FINAL REPORT

For the

U.S. ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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STEAM REFORMING OF METHYL FUEL - PHASE I

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ABSTRACT

An experimental study was made on the effects of gasoline contamination of methanol relative to steam reforming of the mixture.

At the conventional steam reforming temperature of 350-400°F soot was produced with a 90/10 mixture of methanol and gasoline (by weight). A parametric study was conducted to evaluate the effects of higher temperature and higher steam to carbon ratio with four different catalysts.

Soot-free operation was obtained with Girdler catalyst T-2107 at an operating temperature of 750°F at a steam to (total) carbon ratio of 3.8. Essentially all the gasoline is converted into light gaseous hydrocarbons, primarily methane. A trace of light-yellow oil droplets could be detected in the cooled product gas condensate.

A 100 hour test showed no deterioration of the T-2107 catalyst activity under the above conditions.

1.0 PROJECT PROGRAM

1.1 Introduction

Methanol is an excellent fuel for fuel cells. It is more convenient to store than hydrogen. It can be readily steam reformed to hydrogen and CO_2 at relatively low temperatures and low steam/carbon ratios. The U.S. Army Material Development and Readiness Command has developed a methanol steam reforming unit to supply hydrogen to a portable fuel cell power plant of 3KW capacity. During handling and storage of methanol in the field, it could become contaminated with gasoline or diesel fuel. It is difficult to steam reform such contaminated methanol as steam reforming of the hydrocarbons from gasoline or diesel fuel requires breaking of carbon-carbon bonds. This normally requires temperatures of 1200°F or above, while the steam reforming of methanol can take place at 350-400°F.

A contract was granted to JPL to investigate the effect of such hydrocarbon contamination, and to find a potential solution to this problem. The overall objective was to screen a number of promising catalysts over a range of temperatures to find an optimum set of operating conditions for gasification of gasoline contaminated methanol. If such a condition was found, a long duration life time test (100 hours) would be carried out to prove the technical feasibility of the concept.

In previous work at IGT the steam reforming of methanol contaminated with small amounts of ethanol, propanol and butanol was studied. This mixture simulated impure methanol that could be produced from coal processing, and which is normally called methyl fuel. This work showed that carbon deposition would take place on the catalyst at the normal operating temperature of 350-400°F.

It appeared that gasoline would be a worse contaminant to handle than C_2-C_4 alcohols. It was decided to study gasoline contamination first, and that any solution for gasoline contamination should take care of the C_2-C_4 alcohols also.

1.2 Program Goals

The objective of this program was to successfully steam reform methanol contaminated with gasoline. The following goals were to be obtained:

1.2.1 Determine the minimum reactor bed temperature, steam to carbon ratio, and space velocity for methanol/gasoline mixtures with several promising catalysts in order to produce a gasified product that can be utilized in a phosphoric acid fuel cell. This implies that the CO concentration in the product gas should be less than one percent.

1.2.2 Determine the effect of the contaminants on catalyst activity, specifically any reduction in activity by carbon deposition.

1.2.3 Determine the minimum reactor bed temperature and steam to carbon ratio to prevent soot formation.

1.2.4 If successful, demonstrate process feasibility by a continuous 100 hour test conducted at the optimum operating conditions and with the best catalyst.

2.0 TEST DESCRIPTION

2.1 Technical Background

The basic reactions occurring in steam reforming of methanol are

$$CH_3OH + H_2O \rightleftharpoons CO_2 + 3H_2$$

$$CO_2 + H_2 \rightleftharpoons CO + H_2O$$

However, at a temperature of $400^{o}F$ and at atmospheric pressure, the predicted thermodynamic equilbria is as follows:

$$CH_3OH + 1.5\ H_2O \longrightarrow .26\ CO + 0.97\ CO_2 + 0.526\ H_2O + 2.97\ H_2$$

This corresponds to a CO concentration of 0.6 volume percent (wet).

The steam reforming reaction of unleaded gasoline ($CH_{1.94}$) may be described as

$$CH_{1.94} + H_2O \longrightarrow CO + 1.97\ H_2$$

This reaction normally takes place at 1200°F or above over a nickel catalyst. It is not possible to steam reform gasoline by itself at lower temperatures. Thus the big unknown factor at the beginning of this work was what temperature would be required to steam reform mixtures of methanol and gasoline.

These reactions are endothermic i.e., external heat must be supplied through a heat exchanger surface. The carbon monoxide that is formed can react with more steam, if available, according to the shift reaction:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

This reaction is the controlling equilibrium reaction for the production of carbon monoxide or carbon dioxide. At temperatures of 1200°F and above, carbon monoxide is the primary product, while at 350°-400°F, carbon dioxide is the principal product.

Five important parameters to be considered in steam reforming are the steam/carbon molar ratio, the reactor bed temperature, the space velocity, preheat temperature, and catalyst activity and life. Thus the composition of the gases leaving the reforming reactor is dependent on these factors.

In preliminary experiments it was found that methanol and gasoline mix over a wide range of composition, while diesel fuel and methanol form two immiscible layers. Only the lighter fraction of the diesel fuel appears to dissolve in the methanol. Thus it is difficult to define diesel fuel contamination, as it depends on the manner of mixing and the duration of contact between the two phases. In any case the light end of diesel fuel will be similar in composition to gasoline.

It was decided to study a 90/10 methanol/gasoline mixture. The relatively high gasoline percentage was chosen so that any changes in product gas composition due to the presence of gasoline could be measured with reasonable accuracy. Also, if any carbon deposition on the catalyst were to take place, it should be noticeable quite soon, i.e. within a few hours.

2.2 Test Equipment and Test Procedure

The test system is shown schematically in Fig. 2-1. An actual photograph showing the steam reformer is shown in Fig. 2-2. An Inconel reactor with 2.469 inches inside diameter (2-1/2" nominal pipe, sch 40) by 24 inches length was fabricated to fit into an electrically heated furnace. The reaction chamber contains the test catalyst.

The fuel feed tank was filled with premixed methanol/gasoline mixture. Fuel flow as well as water flow were measured using calibrated rotameters in series with orifice meters. Separate electrical heaters preheat and vaporize the reactants. The mixed vaporized fuel and water streams flow downward through the catalyst bed, through a water cooled heat exchanger, through a refrigeration unit, through a condensate collector and then to the atmospheric vent. The reactor has thermocouples to monitor the wall and catalyst temperatures as well as reactant and product temperatures. A sample line after the gas cooling apparatus provides a continuous sample to the gas analyzer for the determination of hydrogen, carbon dioxide, carbon monoxide and volatile hydrocarbon gases.

3.0 RAW MATERIAL SPECIFICATIONS

3.1 Fuels

3.1.1 Methanol

Technical Grade A (procured from Southland Industrial Products of Los Angeles, CA).

3.1.2 Unleaded gasoline, Indolene Clear, Federal test fuel. The chemical composition as determined by Truesdail Lab in L.A. is as follows:

Carbon	83.96%	Wt. Percentage
Hydrogen	13.60%	
Sulfur	0.036%	
Paraffins	70%	Vol. Percentage
Olefins	8%	
Aromatics	22%	

3.2 Catalysts

Four catalysts were evaluated over a range of operating conditions. The physical and chemical characteristics of these catalsyts are given in Table 3-1. Three of these catalysts, namely T-2107-RS, G-66 B-RS and ICI 52-1 are classified as low temperature shift conversion catalysts. Girdler G-56B represents a steam reforming catalyst for hydrocarbons.

Low temperature (480-500^{o}F) and low steam/carbon monoxide ratios are primary objectives for the operating conditions under which these catalysts would perform best in commercial applications. Copper/zinc oxide combinations have been found to be the most effective catalysts wherein the carbon monoxide conversion to carbon dioxide and not to methane or carbon is desired. Within this combination copper is the active catalyst and zinc oxide is the so-called "spacer". The role of zinc oxide is to maintain the copper catalyst as small crystallites and reduce the crystallite growth (thermal sintering) under operating conditions. Small crystallites of copper are much more desirable than large ones because of the higher surface area (hence greater activity) possessed by numerous small catalyst sites. Alumina is also used as a spacer with zinc oxide. Alumina and zinc oxide are different in terms of their aging properties, however. Alumina is an inert oxide which will maintain its oxidation state and structural integrity under these operating conditions (reducing atmosphere and temperatures <570^{o}F) nearly indefinitely. Zinc oxide on the other hand will, although much slower than copper, grow slowly in crystallite size with time thus allowing the copper crystallites to grow also. In addition, zinc oxide is slowly reduced to zinc which will then alloy with copper forming brass. These changes also alter the pore size of the catalyst. Different catalyst preparation techniques have altered the aging processes of these catalysts but prolonged operation of these catalysts at temperatures above their limit (610^{o}F) in the water-gas shift reaction will reduce the lifetime of low temperature operation.

When these low temperature shift catalysts are applied to the steam reforming of methanol, the catalysts are operating under different conditions and catalyzing different reactions. Although some shift reaction probably takes place ($CO + H_2O \rightarrow CO_2 + H_2$) the basic reaction $CH_3OH + H_2O \rightarrow CO_2 + 3H_2$ is similar.

When hydrocarbons such as gasoline are mixed with methanol and this solution is steam reformed conditions different than those used in simple steam reforming of methanol are required. The steam reforming of hydrocarbons requires carbon-carbon bond breakage as well as carbon-oxygen bond formation and therefore follows a different mechanism than the methanol reaction. Different catalysts promote these types of reactions compared to the catalysts effective on the simpler methanol reaction. Further, gasoline is composed of a mixture of hydrocarbons and different carbon-carbon bond strengths, i.e., paraffinic, olefinic and aromatic (including some polynuclear aromatics) with single, double and conjugated bonds respectively. The breakage of these carbon bonds becomes progressively more difficult with the polynuclear aromatics being the most inert. In the attempt to steam reform a methanol-gasoline solution (90/10 wt) at temperatures well below those used in steam reforming of hydrocarbons, the use of low temperature shift catalysts, with slight modifications, was explored. Since the major difficulty in the initial reaction of gasoline is the breaking of carbon-carbon bonds without forming soot the combination of more alumina and higher steam to carbon ratio seemed necessary. In addition to being more stable at higher temperatures, alumina is more acidic than zinc oxide thereby aiding in the initiation of carbon-carbon bond breakage. The series of catalysts which would help bear out the alumina effect was G66B (no alumina), G66C (Al/Cu = 1/1.9), T-2107 (Al/Cu = 1/1), and 52-1 (Al/Cu = 1/1.6). At operating conditions above the manufacturer's suggested temperatures for these shift catalysts the low temperature shift activity may be reduced but the effect on the steam reforming of methanol/hydrocarbon solutions has no precedent from which the manufacturers are able to predict activity or durability. The relatively

unchanged activity of the catalyst T-2107 after 25 hours of steam reforming at various temperatures ranging to as high as 1200°F (exit) indicates that the activity of this catalyst for steam reforming the methanol solution is not dependent on all the same parameters that the shift activity is. Because of the range of temperatures, the accumulated time of operation and the apparent retention of activity compared to the other catalysts, catalyst T-2107 seems to be the best choice for duration testing. The ability for it to maintain activity is presumed to be a combination of high alumina content and low zinc content but other catalysts should be tested before the mechanism can be clearly understood.

4.0 PROCESS PARAMETRIC STUDY

4.1 Results and Discussion

The test data was recorded by two methods:

- o A digital data acquisition system was used to record test data on magnetic tape cassettes for post-run computer data reduction.
- o Manual entries into log sheets were made for operator and engineering observations.

Tables 4-1, 4-2, 4-3 and 4-4 show the measured and reduced data for the steam reforming of a mixture of methanol and gasoline (90/10% by weight) using catalysts T-2107-RS, ICI-52-1, G-66B-RS and G-56B. The steam reformer system was operated over a range of molar ratio of steam to carbon of 1.5 to 15.0 and over a reactor bed exit temperature range of 450 to 1150°F. The correlations and interactions between hydrogen yield, reactor bed exit temperature, steam to carbon ratio, residual gaseous hydrocarbons, carbon monoxide, and soot formation for each catalyst tested are discussed below under respective sub-sections.

4.1.1 Hydrogen Yield

The hydrogen yield in these test runs is defined as the ratio of the actual amounts of hydrogen produced under the test conditions to the maximum amount of hydrogen that could have been produced from the input fuel for 100% conversion of both methanol and gasoline. This ratio is expressed as

$$\frac{[H_2]}{3\{[CO]+[CO_2]+[CH_4]\}}$$

where the square brackets indicate dry volume percentages in the product gas. It should be noted that 19% of the total carbon input comes from the gasoline. Figures 4-1, 4-2, 4-3, 4-4 and 4-5 show the correlation between hydrogen yield, reactor bed exit temperature and steam to input carbon molar ratio for catalysts T-2107, IC152, G-66B-RS, G-56B and all these four catalysts together respectively. From Figure 4-1 through 4-3 it is evident that for every $100^{O}F$ increase in reactor bed temperature there is 3.8% decrease in direct hydrogen yield. It is also apparent that as the steam to carbon ratio is increased, the hydrogen yield increases. The decrease in hydrogen yield with increase in temperature or decrease in steam to input carbon molar ratio is due to the water-gas shift reaction.

In Figure 4-1 the areas enclosed by $A_1A_2B_2B_1$, $B_1B_2C_2C_1$ and $C_1C_2D_2D_1$ show the hydrogen yield with respect to bed exit temperature for steam to carbon ratios of 1.5, 3.0 and 6.0 respectively. The variation in space velocity accounts for the spread of data for the same steam to carbon ratio. The same observation holds true for the Figures 4-2 through 4-4.

Figures 4-1 to 4-3 also indicate that the hydrogen yield is higher with catalyst T-2107-RS than with ICI-52 and G-66B-RS under identical reactor bed exit temperatures and steam to carbon ratios.

The hydrogen yield for catalyst G-56B (Figure 4-4) indicates that this catalyst has very little activity below $1000^{O}F$. This was to be expected as G-56B is a steam reforming catalyst for hydrocarbons. The hydrogen yield increases rapidly with an increase in temperature above $1000^{O}F$.

Figure 4-5 shows the data for all four catalysts on one plot. As such it is a generalized plot of hydrogen yield vs. reactor bed exit temperature. This plot shows how the data points can be grouped under steam to carbon ratios of 1.5 (area $A_1A_2B_2B_1$), 3.0 (area $B_1B_2C_2C_1$)and 6.0 (area $C_1C_2D_2D_1$). The hydrogen yield is strongly dependent on steam to carbon ratio and on the reactor bed exit temperature, and not so much on the catalyst.

It should be noted that the plots of

$$\frac{[H_2]}{3\{[CO]+[CO_2]+[CH_4]\}}$$

do not represent the ultimate yield of hydrogen. The product may be cooled down to 400°F and passed over a low temperature shift catalyst bed to convert most of the CO to more hydrogen.

4.1.2 Gaseous Hydrocarbons

The gaseous hydrocarbon fraction is defined as the ratio of the moles of hydrocarbons in the product gas stream to moles of output carbon, where the latter are the total moles of carbon monoxide, carbon dioxide and hydrocarbons in the product gas stream. The gaseous hydrocarbon fraction is essentially all methane. Figure 4-6 indicates the correlation between the gaseous hydrocarbons, the reactor bed exit temperature and soot formation. Data points with soot formation are shown by shaded symbols.

If all the gasoline present is converted to methane, and none of this methane is steam reformed to hydrogen, then the maximum methane will be 19.4% for a 90/10% by wt. methanol/gasoline mixture. This is shown by the dotted line in Figure 4-6. So for values of methane below 19.4%, we may assume that some of this methane has been steam reformed into hydrogen. For values of CH_4 above 19.4%, we may assume that some of the methanol is converted to methane. This explanation also applies to column of $CH_4/.1914 \; CO+CO_2+CH_4$ in Tables 4-1 to 4-4.

The occurance of soot formation was determined from the amount of soot particles collected in the condensate from the product gas. This soot formation was rated on the scale of 0 to 10, zero being soot free and 10 representing an appreciable amount of soot. This qualitative rating is tabulated in Tables 4-1 to 4-4 for each test run. The data points with soot formation are marked with shaded symbols in Figure 4-6.

The data points in the zone below the solid line are essentially soot free for steam carbon ratios above 6.0, while most of the data points in the zone above the solid line have varying degrees of soot formation for S/C ratios below 3.0. The negative slope of the solid line indicates that more methane is steam reformed at higher temperature. This plot also indicates that soot formation is accompanied by higher methane contents in the product gas stream.

4.1.3 Carbon Monoxide

Figure 4-7 shows the effect of reactor bed exit temperature and steam to carbon ratio on the carbon monoxide concentration. It also identifies the data points with soot formation by shaded symbols (as discussed in Section 4-2). From this plot it is evident that carbon monoxide concentration increases as the reactor bed exit temperature increases or as the steam to carbon ratio decreases. This is obviously in line with the equilibrium of the water gas shift reaction.

4.1.4 Liquid Hydrocarbons in Condensate

Some of the condensate from the product gas had an oily film or oily droplets floating on top of the water level while other samples were essentially oil free. Perhaps a better description of the oil might be a yellow liquid hydrocarbon. This oil formation was rated on a scale of 0 to 10, zero being oil free and 10 representing an appreciable amount of oil. This qualitative rating is tabulated in Tables 4-1 to 4-4 for each test run. A rating of five might represent on the order of a percent of the gasoline throughput.

Figure 4-8, a photograph of four condensate samples taken from test runs with exit temperatures of 600, 650, 700 and 750°F with catalyst T-2107-RS indicates very clearly that as the reactor bed exit temperature increases, the yellowish coloration caused by the presence of oil droplets decreases. An analysis

of this yellow liquid hydrocarbon showed that it is similar to the heavy end of the gasoline. It proved to be very difficult to obtain representative condensate samples in short duration runs. The samples in Figure 4-8 were in fact from the 100 hour test of catalyst screening.

4.2 Conclusions

The experiments described above lead to the following conclusions:

1. It appears to be possible to gasify the gasoline in the methanol during steam reforming of the mixture. The gasoline is almost totally converted into methane. Trace amounts of the gasoline are converted into a yellow liquid hydrocarbon that is probably gaseous at 300^{o}F (to be confirmed) and condenses out at room temperature. The presence of these trace amounts of hydrocarbons should not affect fuel cell operation at 300^{o}F or above.
2. The above results can be obtained at temperatures in the range of 650-750^{o}F, at steam to carbon molar ratios of approximately 5, and at input space velocities of 1600 hour^{-1} (STP), utilizing catalyst T-2107-RS.
3. Soot formation takes place at temperatures below 650-750^{o}F and/or at steam to carbon ratios below 5.
4. It is difficult to get good data on soot and residual liquid hydrocarbon formation in short duration tests of a few hours. To test the validity of the above results, and also obtain an indication of the stability of the catalyst, a long duration test is essential.

It was decided to utilize catalyst T-2107-RS for the 100 hour test because of its good performance over a wide temperature range, and because of its apparent high temperature stability.

5.0 100 HOUR TEST

5.1 Test Procedure

The process feasibility was demonstrated by operating the steam reforming

system continuously for one hundred hours without any major problems and by shutting the system down voluntarily.

The process schematic and the test equipment for this test were the same as those reported in Section 2.0 except thermocouple 68 was relocated to the top of the bed in the gaseous phase region. The reactor was filled with a new batch of catalyst T-2107-RS up to a bed height of 10". The catalyst pellets were of 3/16" x 3/16" size and the weight of the catalyst was 2 lbs (896 gms). The test was started on 5/9/77 (Monday) at noon. The reactor bed exit temperature was measured by TC-55 at one inch from the bottom of the catalyst bed. This thermocouple was located inside the thermowell in the center of the reactor.

For the first seventeen hours the reactor bed exit temperature was controlled at 630°F (the maximum temperature recommended by the catalyst manufacturer for low temperature shift conversion) and at a steam to carbon molar ratio of 3.8. However, at these operating conditions liquid hydrocarbons were found in the condensate stream indicating a portion of the gasoline in the feed was neither steam reformed nor converted to gaseous hydrocarbons. To reduce these liquid hydrocarbons the steam to carbon molar ratio was increased and decreased to 5.2 and 2.5 respectively, but the effect was nil so after 27 hours of operation the reactor bed exit temperature was raised to approximately 690°F. At this temperature the amount of liquid hydrocarbons in the condensate had decreased, but was still appreciable. So after 39 hours reactor bed exit temperature was raised to 770°F and the steam to carbon molar ratio was varied from 3.8 to 5.1. Finally after 65 hours of operation the reactor bed exit temperature was raised to 820°F, and the steam to carbon molar ratio was increased from 3.8 to 4.7. At these operating conditions the liquid hydrocarbons in the condensate stream were completely eliminated. The test was terminated voluntarily after 102 hours of continuous operation. Figure 5-7 shows the variation in temperature with time (to be discussed more later).

Figures 5-1 and 5-2 show the variation in space velocity and steam to carbon molar ratio for 100 hours of test operation. The average space velocity was 1050 hr^{-1} and the steam to carbon molar ratio was varied from 3.8 to 5.2.

Space velocity is defined as the volumetric rate of flow of the input gases, measured at standard temperature and pressure, divided by the volume of the catalyst bed, expressed as $hours^{-1}$. Unless noted otherwise, this is the space velocity used in this report. Another definition of space velocity is in use based upon the output of hydrogen. This "hydrogen space velocity" may be defined as the volumetric flow rate of hydrogen product gas, measured at standard temperature and pressure, divided by the volume of the catalyst bed, expressed as $hours^{-1}$. Both space velocities are shown in Tables 4-1 through 4-4.

5.2 Results and Discussion. The test data was recorded by two methods: A digital data acquisition system was used to record test data on magnetic tape cassettes for post-run computer data reduction. Manual entries into log sheets were made for operator and engineering observations.

Table 5-1 shows the measured and reduced data for the hundred hour test run. The steam reformer system was operated over a range of molar steam to carbon ratios of 3.5 to 5.2 and over a reactor bed exit temperature range of 600 to 820°F. The correlations and interactions between hydrogen yield, reactor bed exit temperature, steam to carbon molar ratio, residual gaseous hydrocarbons, carbon monoxide, hydrogen, carbon dioxide and space velocity are discussed below under respective sub-sections.

5.2.1 Hydrogen Yield. Figure 5-3 shows the correlation between hydrogen yield as defined in section 4.1 and the reactor bed exit temperature for catalyst T-2107-RS during 100 hours of test operation. From this figure it is evident that as the reactor bed temperature increases there is a decrease in the hydrogen yield due to the water-gas shift reaction. This confirms the earlier observation made in section 4.1.1. The hydrogen yield above 100% reported in

Figure 5-3 indicates soot formation in the reactor as the denominator term in the definition of the hydrogen yield assumes no soot formation. This soot formation was confirmed by the ratio of "carbon out" to "carbon in" given in Table 6-1 The comparison of Figures 4-1 and 5-3 indicates that under similar operating conditions namely reactor bed exit temperature, steam to carbon molar ratio and space velocity, a higher hydrogen yield was obtained in the 100 hour test run than in the short duration tests. The catalyst in the short duration tests was subjected to very high temperatures (1200°F), which in turn might have decreased the activity of the catalyst. This is probably the reason for the different results.

5.2.2 Gaseous Hydrocarbons

The gaseous hydrocarbon fraction, primarily CH_4 is defined in Section 4.2. Figure 5-4 shows the correlation between the gaseous hydrocarbons and the reactor bed exit temperature. From this figure it is apparent that the amount of gaseous hydrocarbons decreases as the reactor bed exit temperature increases. More methane is steam reformed into hydrogen at higher temperatures. This agrees with the observation made in Section 4.1.2. However, the comparison of Figures 5-4 and 4-6 indicates that under similar operating conditions the gaseous hydrocarbons formation was considerably less in the 100 hour test run than the short duration tests. As for hydrogen, the explanation probably lies in lower activity of the catalyst in the short duration tests due to high temperature exposure

5.2.3 Product Distribution

5.2.3.1 Experimental Measurements

Figures 5-5 and 5-6 show the composition of hydrogen, carbon dioxide, carbon monoxide and methane on a dry basis. It is evident from Figure 5-5 that the hydrogen yield remained at approximately the same level throughout the 100 hours of test operation. This indicates no reduction in activity of the catalyst T-2107 even at temperatures of 820°F and after long duration testing. It is also evident that the concentration of CO_2, CH_4 and CO in the product gas also stayed essentially constant.

5.2.3.2 Comparison of Experimental Results with Equilibrium Prediction

The theoretical equilibrium gas compositions for methanol-gasoline mixtures was calculated with the CEC 71 JANNAF Thermodynamic Equilibrium program and are plotted vs. steam to carbon molar ratio in Figure 5-9 for the reactor bed temperature of 800°F at a pressure of 1 atm. The experimental values of product composition (H_2, CO_2, CO, CH_4), as measured at a reactor bed temperature of 800°F and a steam to carbon molar ratio of 3.8 and 4.8, are also shown in Figure 5-9. This figure indicates that essentially all of the gasoline in the fuel is steam reformed to hydrogen, instead of hydrogenated to methane. This conclusion may be drawn from the low CH_4 concentration (0.8%) that was measured relative to the high CH_4 concentration predicted at equilibrium (8.5%).

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

For each mole of methane that is steam reformed there will be produced four moles of hydrogen and one mole of carbon dioxide, while two moles of water are consumed. If we subtract the experimental CH_4 concentration from the equilibrium value, and convert the difference into hydrogen by steam reforming, we obtain additional hydrogen, namely 26.1 volume percent. If we now add this extra hydrogen to the equilibrium hydrogen, it adds up to a value of 41.9 volume percent. This is in good agreement with the experimental value of 41.1 % H_2. In the same way, the water content would decrease to 43.0%, which compares well with an experimental value (derived) of 44.0%. In other words, the higher than equilibrium hydrogen can be explained in a satisfactory manner this way.

5.2.4 Reactor Temperature Profile

Figure 5-7 shows the reactor bed exit temperature measured by TC-55 at 1" above the bottom of the bed, as well as the gas preheat temperature measured by TC-68. The reactor bed exit temperature was raised from 600°F to 820°F in several steps as discussed in section 5.1. As the reactor bed exit temperature was raised by an external heat source, it also raised the preheat temperature of

the mixture of steam and fuel vapors. This was partly due to the reactor tube being only half full, and the top half thus acting as a prechamber. The gas preheat temperature was approximately 180 to 210°F higher than the reactor bed exit temperature. This temperature drop from the preheat zone to the bed exit thus provided part of the required heat of the endothermic reaction. It should be noted that the preheat temperature should be above the minimum soot temperature, i.e, the temperature below which soot will deposit on the catalyst. Even so, the preheat temperature was higher than needed.

The thermocouples TC-52 and TC-53 measure the wall temperature of the reactor at the 10" and 5" levels from the bottom of the reactor bed respectively. Thermocouple TC-55 measures the temperature of the catalyst bed in the center of the reactor at 10" and 5" level from the bottom ot the reactor. Figure 5-8 shows the temperature gradient from the reactor wall to the center of the reactor at the same height of the reactor bed. It indicates that there is about 10° - 20°F and 20° - 40°F temperature drop from the wall to the center of the bed at the top and the middle of the reactor bed respectively. This small ΔT indicates a low heat transfer rate, which is consistent with the high preheat temperature discussed earlier.

5.2.5 Liquid Hydrocarbons in Condensate

As discussed in Section 5.1, some of the condensate samples had a yellowish looking oily film or oily droplets floating on top of the water level at lower bed temperatures. However, this was essentially eliminated as the temperature of the reactor bed was increased to 820°F. This oil represents the heavy end of the Indolene as an analysis indicated that 90% of the sample had a boiling point near the top end of the b.p. of Indolene. It was also found that the olefinic and aromatic content of the yellowish oil was higher than for Indolene.

6.0 CONCLUSIONS

1. Methanol contaminated with gasoline can be gasified in a conventional methanol steam reformer to produce a hydrogen-rich gas suitable for utilization in a phosphoric acid fuel cell. However, more severe operating conditions must be used and a slightly lower quality product gas is produced.

2. It has been found for a 90/10 methanol/gasoline (by weight) mixture that an operating temperature of 650-750^{o}F is required. At these temperatures essentially all of the gasoline is converted into gaseous hydrocarbons, primarily methane. At 650^{o}F traces of a light yellow hydrocarbon liquid are present in the product gas (after cooling). At 750^{o}F this yellow oil is reduced to a minor trace, which at 820^{o}F had totally disappeared. It appears that the yellow oil represents the heavy end of the gasoline. As such it should be a vapor at the fuel cell stack temperature, and should not interfere with the stack operation. However, experiments with an actual fuel cell are needed to confirm this.

3. A steam to carbon ratio of 3.8 was required to prevent soot formation and at the same time minimize the yellow oil in the condensate. A minimum temperature of 650^{o}F was required to prevent soot formation. This implies that the minimum preheat temperature must be above 650^{o}F. It appears that a lower gasoline content mixture can be processed with a lower steam to carbon ratio.

4. The T-2107 catalyst has shown good activity over a wide range of operating conditions, specifically temperature. It has retained its activity over the 100 hour test and shows good prospects for long life.

5. The carbon monoxide content of the product gas in the 100 hour test was 1.5 - 2.0%. This is somewhat above the 1% maximum level that is normally specified for a phosphoric acid cell. Operation at this higher CO level will result in somewhat lower performance. A definite way of

lowering the CO content is to cool the product gas to 400°F and to pass it over a small bed of low temperature shift catalyst (e.g. T-2107).

6. The sulfur in the gasoline (0.03 weight percent) will poison the T-2107 catalyst in time. The copper and zinc are converted into sulfides which are not catalytically active. To prevent this a bed of zinc oxide can be placed between the fuel/steam preheater and the steam reformer. Periodic replacement of the zinc oxide bed will insure that the bed does not become saturated.

The zinc oxide will not remove all sulfur compounds, so that prolonged operation on gasoline contaminated methanol will slowly poison the catalyst with sulfur. A possible remedy would be to use high temperature shift converter catalyst (Fe), as FeS has catalytic activity. To confirm this further experimental work is required.

7. The following hardware changes to the conventional steam reformer should be made to enable operation on methanol that is contaminated with gasoline or diesel fuel:

a. increase preheater size (to reach 650°F preheat)

b. add zinc oxide bed between preheater and steam reformer to remove sulfur compounds

c. increase the heat transfer rate to the steam reformer tubes to accomodate higher steam to carbon ratio (3.8) and a higher bed temperature (650-750°F)

d. possibly provide product cooling to 400°F and a secondary low temperature shift converter to reduce the carbon monoxide content below one percent.

Table 3-1

Physical and Chemical Characteristics of Test Catalysts

Trade Name	Girdler* T-2107-RS	Girdler* G-66B-RS	Girdler G-56B	ICI* 52-1
Particle Size, Inches	1/8" x 1/8"	1/4" x 1/8"	1/8" x 1/8"	1/8" x 3/16"
Bulk Density, lbs/cu.ft.	N/A	80	53 ± 4	165
Chemical Analysis				
% Al	10.7	<0.06	74.0	5.29
% Cu	33.1	25.5	0.0	20.1
% Zn	16.3	51.9	0.0	35.2
% Ni	0.0	0.0	25.0	0.0

* By Pomeroy, Johnston and Bailey Lab.

Table 4-1

Test Results of Steam Reforming of Methanol/Gasoline (90/10 % by Wt.)

Catalyst T-2107 RS

Run No.	Scan No.	Catalyst: Wt. in Gms.	Catalyst: Length in Inches	Space Velocity in Hr^{-1}: Input (Fuel/Water)	Space Velocity in Hr^{-1}: Output (Hydrogen)	Flow Rate: Fuel in Lbs/Hr	Flow Rate: Water in Lbs/Hr	Molar Ratio of Steam to Carbon S/C	Temperature: Preheat °F	Temperature: Bed Exit °F	Volumetric Product Gas Compn. % (Dry Basis): H_2	CO_2	CO	CH_4	$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$ %	Comments: Carbon Soot Form.	Comments: Oily Films in Condensate
[illegible]*	1	1030	11	1939	1054	1.33	2	2.7	556	652	71.1	20.6	5.5	2.7	9.4	82.3	48.3	0	0
	2	1030	11	1939	1238	1.33	2	2.7	556	770	69.6	19.2	8.2	3.0	9.9	76.3	50.9	0	0
286	1	1030	11	1616	506	0.5	2	6.3	590	530	69.5	20.8	5.7	4.0	13.1	76.0	67.5	0	0
	2	1030	11	899	309	0.5	1	3.1	520	520	71.1	21.3	3.6	4.0	13.8	82.0	71.0	0	0
	3	1030	11	541	517	0.5	0.5	1.6	524	474	68.7	20.5	6.7	4.1	13.1	73.2	67.4	4	0
[illegible]	1	1030	11	900	476	0.5	1	3.1	493	744	68.5	18.6	8.7	4.2	13.3	72.5	68.6	0	0
	2	1030	11	541	445	0.5	0.5	1.6		746	66.5	13.7	15.3	4.5	13.4	66.2	69.1	4	0
[illegible]	1	1030	11	3247	2853	0.3	3	16.0	616	725	67.9	21.1	5.5	5.6	17.4	70.3	89.5	6	4
	2	1030	11	2623	2623	0.3	3	16.0	617	996	65.6	15.9	12.8	5.7	16.7	64.1	85.9	7	0
[illegible]	1	1030	11	904	458	0.5	1	3.1	521	754	68.1	19.2	7.4	5.2	16.4	71.4	84.1	4	0
	2	1030	11	904	471	0.5	1	3.1	521	644	68.2	19.9	6.8	5.1	16.1	71.5	82.5	3	0
	3	1030	11	904	471	0.5	1	3.1	537	870	68.2	19.9	6.4	5.2	16.0	69.0	82.0	0	0
[illegible]	1	1030	11	3616	1561	2	4	3.1	652	1110	67.1	18.9	6.5	7.5	22.8	68.0	117.3	5	5
	2	1030	11	1808	780	1	2	3.1	595	890	67.1	18.9	6.5	7.5	22.8	68.0	117.0	2	6
291	1	1030	11	1780	724	1	2	3.1	613	790	71.1	16.2	6.9	5.7	19.8	82.3	101.8	0	2
292	1	1030	11	2405	1333	1.3	2.7	3.1	630	781	69.5	20.4	6.3	3.7	12.2	76.2	62.6	0	2
	2	1030	11	1610	527	0.5	2	6.3	589	793	70.8	21.1	5.1	3.0	10.3	80.8	52.8	1	3
[illegible]	1	1030	11	1616	490	0.5	2.0	6.3	585	795	70.3	20.2	5.8	3,7	12.2	78.9	64.0	0	0
[illegible]	1	1030	11	3657	217	0.2	5.0	15.5	569	1043	70.1	21.2	5.5	3.1	10.4	78.4	53.5	0	2
[illegible]	1	1030	11	1580	370	0.4	2.0	7.8	434	1046	71.2	18.8	6.6	3.4	11.8	82.5	60.7	0	2
	2	1030	11	2160	796	0.8	4.0	7.8	631	056	69.5	20.1	6.4	3.9	12.8	76.2	66.0	0	2

* These test runs are with pure methanol only.

Table 4-2

Test Results of Steam Reforming of Methanol/Gasoline (90/10 % by Wt.)

Catalyst ICI-52-1

Run No.	Scan No.	Catalyst		Space Velocity in Hr^{-1}		Flow Rate		Molar Ratio of Steam to Carbon S/C	Temperature		Volumetric Product Gas Compn. % (Dry Basis)				$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$ %	Comments	
		Wt. in Gms.	Length in Inches	Input (Fuel/Water)	Output (Hydrogen)	Fuel in Lbs/Hr	Water in Lbs/Hr		Preheat ^oF	Bed Exit ^oF	H_2	CO_2	CO	CH_4				Carbon Soot Form.	Oily Films in Condensate
283	2	936	11	2333	519	3	6	9.3	650	561	71.0	25	0.4	3.7	12.8	81.3	65.8	2	4
284	1	2020	22	1166	256	0.5	3	9.3	638	558	69.2	21.3	5.3	4.2	13.6	74.9	70.0	1	0
	2	2020	22	1166	256	0.5	3	9.3	652	600	69.3	20.5	6.1	4.1	13.4	75.3	68.9	0	0
	3	2020	22	810	203	0.5	2	6.3	594	604	68.9	20.7	5.9	4.8	14.7	73.6	75.6	2	0
285	1	2020	22	499	244	0.5	1	3.1	512	557	69.0	21.0	4.0	4.0	14.0	79.3	72.0	0	0
	2	2020	22	270	234	0.5	1	1.6	512	483	69.0	19.0	7.6	4.5	14.5	74.0	74.6	6	0
	3	2020	22	270	234	0.5	1	1.6	512	589	67.7	16.6	11.0	4.4	14.0	70.5	72.0	4	0

Table 4-3

Test Results of Steam Reforming of Methanol/Gasoline (90/10 % by Wt.)

Catalyst G-66B-RS

Run No.	Scan No.	Catalyst		Space Velocity in Hr^{-1}		Flow Rate		Molar Ratio of Steam to Carbon S/C	Temperature		Volumetric Product Gas Compn.				$\frac{CH_4}{CO+CO_2+CH_4}$	$\frac{H_2}{3(CO+CO_2+CH_4)}$	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$	Comments	
		Wt. in Gms.	Length in Inches	Input (Fuel/Water)	Output (Hydrogen)	Fuel in Lbs/Hr	Water in Lbs/Hr		Preheat ^oF	Bed Exit ^oF	% (Dry Basis) H_2	CO_2	CO	CH_4	%	%	%	Carbon Soot Formn.	Oily Films in Condensate
301	1	1469	11	3233	998	1	4	6.3	681	571	69.9	19.5	7.1	3.5	11.6	77.4	59,8	0	6
	2	1469	11	1799	958	2	2	3.1	665	680	69.3	21.2	4.7	4.8	15.7	75.2	80,4	0	3
302	1	1469	11	2516	840	1	3	4.7	667	767	68,2	20.6	5.7	5.3	16,7	71.9	86.3	3	5
303	1	1469	11	1799	961	1	2	3.1	593	840	68.2	20.5	6.2	5.1	16.1	71.5	82,5	3	7
	2	1469	11	2099	1832	1.82	2	1.7	592	750	69.8	21.1	5.1	4,0	13.3	77.1	68.1	3	4
304	1	1469	11	2516	1015	1	3	4.7	667	862	68.7	20.2	6.1	5.1	16.2	72.9	83.6	2	3

Table 4-4

Test Results of Steam Reforming of Methanol/Gasoline (90/10 % by Wt.)

Catalyst C-56B

Run No.	Scan No.	Catalyst		Space Velocity in Hr^{-1}		Flow Rate		Molar Ratio of Steam to Carbon S/C	Temperature		Volumetric Product Gas Compn. % (Dry Basis)				$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$ %	Comments	
		Wt. in Gms.	Length in Inches	Input (Fuel/Water)	Output (Hydrogen)	Fuel in Lbs/Hr	Water in Lbs/Hr		Preheat °F	Bed Exit °F	H_2	CO_2	CO	CH_4				Carbon Soot Form.	Oily Films in Condensate
[illegible]*	1	552	5.5	2150	1473	1	1	1.8	496	1100	67.3	11.0	17.7	4.0	12.23	68.6	62.9	0	0
	2	552	5.5	2473	862	0.35	16	8.3	478	1107	73.5	22.4	3.7	0.3	1.14	92.8	5.8	0	0
	3	552	5.5	1938	1072	1.33	.66	0.9	414	1106	65.7	7.0	22.4	5.8	16.5	62.2	84.9	0	0
[illegible]	1	552	5.5	3598	2213	1	2	3.1	473	974	68	15.4	9.8	1.2	4.8	85.9	24.5	0	0
[illegible]	1	552	5.5	2165	1502	1	1	1.6	519	1131	70.2	6.8	20.5	2.5	8.4	78.5	43.2	0	0
	2	552	5.5	3247	2408	1.5	1.5	1.6	576	1080	69.9	8.0	20.0	2.2	7.3	77.2	37.5	0	0
	3	552	5.5	4330	3193	2	2	1.6	676	1020	67.7	9.7	18.8	3.9	11.2	69.7	61.9	0	0
	5	552	5.5	2165	1330	1	1	1.6	553	1047	64.7	9.4	18.3	7.6	21.5	61.1	110.8	1	0
256	1	552	5.5	2165	1505	1	1	1.6	510	1057	66.9	10.9	16.8	5.4	16.3	67.4	83.9	1	0
	2	552	5.5	2165	1567	1	1	1.6	514	1139	69.5	7.2	20.7	2.6	8.4	76.0	43.4	1	0

*These test runs are with pure methanol only.

Table 5-1

(100 Hour Test Run)

Test Results of Steam Reforming of Methanol/Gasoline (90/10 % by Wt.)

Catalyst T-2107-RS

Page 1 of 4

[illegible]	Scan No.	Space Velocity in HR^{-1} Input (Fuel/Water)	Flow Rate Fuel in Lbs/hr	Flow Rate Water in Lbs/hr	Molar Ratio of Steam to Carbon S/C	Temperature Preheat ^oF	Temperature Bed Exit ^oF	Volumetric Produce Gas Compn. % (Dry Basis) H_2	CO_2	CO	CH_4	$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$ %	$\frac{C_{out}}{C_{in}} \times 100$
[illegible]	Start														
[illegible]	[illegible]	1362	0.45	1.5	5.2	677	525	74.6	23.1	0.6	1.7	6.7	97.9	34.8	82.3
[illegible]	[illegible]	1047	0.45	1.1	3.8	685	450	74.0	23	1.3	1.8	6.9	94.5	35.4	
[illegible]	3	1047	0.45	1.1	3.8	787	577								
[illegible]	[illegible]	1047	0.45	1.1	3.8	787	584	74.8	23.4	0.5	1.3	5.2	98.9	26.7	83.2
	[illegible]	1047	0.45	1.1	3.8	832	622								
[illegible]	[illegible]	1047	0.45	1.1	3.8	829	628								
	[illegible]	1047	0.45	1.1	3.8	831	629	74.0	23.5	1.1	1.4	5.4	94.9	27.7	90.2
	[illegible]	1047	0.45	1.1	3.8	832	[illegible]								
[illegible]	[illegible]	1047	0.45	1.1	3.8	851	625								
	[illegible]	1047	0.45	1.1	3.8	847	629								
[illegible]	[illegible]	1047	0.45	1.1	3.8	846	633	75.3	22.4	0.9	1.5	6.04	101.2	31.0	76.3
[illegible]	[illegible]	1047	0.45	1.1	3.8	843	641								
[illegible]	[illegible]	1047	0.45	1.1	3.8	844									
[illegible]	[illegible]	1047	0.45	1.1	3.8	838	623								
[illegible]	[illegible]	1047	0.45	1.1	3.8	844	640	79.2	18.2	0.9	1.6	7.7	127.5	39.5	46.2
	[illegible]	1047	0.45	1.1	3.8	842	645								
[illegible]	[illegible]	519	0.315	0.5	2.5	863	626	77.4	19.1	1.5	2.0	8.85	114.2	45.4	54.0
[illegible]	[illegible]	[illegible]	0.24	0.5	3.3	869	638	76.6	20.6	1.0	1.8	7.7	109.1	39.5	62.0
[illegible]	20	726	0.24	0.8	5.2	868	624	76.8	20.6	0.8	1.8	7.76	110.3	39.8	60.0
[illegible]	21	726	0.24	0.8	5.2	868	702	75.5	21.6	1.1	1.7	7.38	105.3	37.9	71.0
	[illegible]	554	0.3	0.55	2.9	909	706	75.2	21.9	1.2	1.7	6.86	101.1	35.2	74.0
	[illegible]	[illegible]	0.41	1.1	4.2	904	699	75.2	21.9	1.2	1.7	6.86	101.1	35.2	74.0
	[illegible]	[illegible]	0.36	1.1	4.8	865	685								
[illegible]	[illegible]	[illegible]	0.45	1.1	3.8	893	711	73.6	24.1	1.1	[illegible]	4.55	92.9	23.4	98.0
	[illegible]	[illegible]	0.45	1.1	3.8	891									

TABLE 5-1

Time	Scan No.	Space Velocity in HR^{-1}: Input (Fuel/Water)	Flow Rate: Fuel in Lbs/hr	Flow Rate: Water in Lbs/hr	Molar Ratio of Steam to Carbon S/C	Temperature: Preheat ^oF	Temperature: Bed Exit ^oF	Volumetric Produce Gas Compn. % (Dry Basis): H_2	CO_2	CO	CH_4	$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949\,(CO+CO_2+CH_4)}$ %	$\frac{C_{out}}{C_{in}} \times 100$
1800	30	1050	0.45	1.1	3.8	901	698	74.1	23.2	1.4	1.3	5.02	95.4	25.8	89.5
1900	31	1050	0.45	1.1	3.8	898	683								
2000	32	1050	0.45	1.1	3.8	899									
2100	33	1050	0.45	1.1	3.8	902									
2200	34	1050	0.45	1.1	3.8	901	678	73.3	22.9	2.5	1.3	4.87	91.5	25.0	96.7
2300	35	1050	0.45	1.1	2.8	965	747								
2400	36	1050	0.45	1.1	3.8	962	752	73.6	23.1	2.3	1.0	3.79	93.0	19.5	97.7
5/11/77															
0200	37	1050	0.45	1.1	3.8	962	752								
0200	38	1050	0.45	1.1	3.8	963	757	73.9	23.1	1.7	1.3	5.0	94.4	25.7	91.0
0300	39	1050	0.45	1.1	3.8	960	753								
0400	40	1050	0.45	1.1	3.8	961	750								
0500	41	1050	0.45	1.1	3.8	960	756								
0600	42	1050	0.45	1.1	3.8	964	749	73.8	23.1	1.9	1.3	4.94	93.5	25.3	92.4
0700	43	1031	0.41	1.1	4.2	963	756	74.6	22.2	2.0	1.2	4.72	98.0	24.2	83.0
0800	44	1031	0.41	1.1	4.2	965	758								
0900	45	1031	0.41	1.1	4.2	963	761	74.2	23.2	1.3	1.3	5.04	95.9	25.9	88.8
1000	46	1031	0.41	1.1	4.2	961	761								
1100	47	1031	0.41	1.1	4.2	960									
1200	48	991	0.31	1.1	5.6	960	756	73.5	22.8	2.4	1.3	4.91	92.5	25.2	95
1300	49	917	0.40	0.96	3.8	962									
1400	50	921	0.41	0.96	3.8	962	758	74.0	23.4	1.3	1.3	5.0	95.0	25.7	90.9
1500	51	1030	0.41	1.1	4.2	961	761	73.9	22.7	2.2	1.2	4.6	94.0	23.6	91.0
1600	52	1003	0.34	1.1	5.1	957	781								
1700	53	1003	0.34	1.1	5.1	959									
1800	54	1003	0.34	1.1	5.1	958	770	78.0	19.4	1.2	1.5	6.8	117.6	34.9	53.8
1900	55	1003	0.34	1.1	5.1	955	783								
2000	56	1003	0.34	1.1	5.1	953	776								
2100	57	1003	0.34	1.1	5.1	953	781								
2200	58	1003	0.34	1.1	5.1	956	782	74.5	22.8	1.3	1.4	5.88	97.4	30.2	83.7
2300	59	1047	0.45	1.1	3.8	953	734								
2400	60	1047	0.45	1.1	3.8	960	758	73.4	23.3	2.0	1.3	4.9	92.0	25.1	97.8

TABLE 5-1

Time	Scan No.	Space Velocity in HR^{-1} Input (Fuel/Water)	Flow Rate: Fuel in Lbs/hr	Flow Rate: Water in Lbs/hr	Molar Ratio of Steam to Carbon S/C	Temperature: Preheat ^oF	Temperature: Bed Exit ^oF	Volumetric Produce Gas Compn. % (Dry Basis): H_2	CO_2	CO	CH_4	$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{.1949 (CO+CO_2+CH_4)}$ %	$\frac{C_{out}}{C_{in}} \times 100$
5/12/77															
0100	61	1047	0.45	1.1	3.8	1019	808	73.8	23.4	1.5	[illegible]	5.0	93.9	25.7	94.0
0200	62	1047	0.45	1.1	3.8	1016									
0300	63	1047	0.45	1.1	3.8	1016									
0400	64	1047	0.45	1.1	3.8	1017									
0500	65	1047	0.45	1.1	3.8	1014	803	72.6	23.3	2.6	[illegible]	5.47	88.3	28.1	104.3
0600	66	1047	0.45	1.1	3.8	1015									
0700	67	1047	0.45	1.1	3.8	1016	806	73.4	24.	1.3	[illegible]	4.9	92.0	25.1	100.2
0800	68	1047	0.45	1.1	3.8	1014	825								
0900	69	1047	0.45	1.1	3.8	1015	826								
1000	70	1047	0.45	1.1	3.8	1015	808								
1100	71	1047	0.45	1.1	3.8	1014									
1225	72	1015	0.37	1.1	4.8	1016	808	72.7	24.1	2.0	[illegible]	4.74	88.4	24.3	109.2
[illegible]	73	1015	0.37	1.1	4.8	1013	830								
[illegible]	74	1043	0.44	1.1	3.8	1013	827								
1500	75	1015	0.37	1.1	4.8	1014									
1600	76	1011	0.36	1.1	4.8	1015	811	72.2	23.9	1.9	2.0	7.19	86.6	36.9	100.4
1700	77	1011	0.36	1.1	4.8	1015	845								
1800	78	1011	0.36	1.1	4.8	1014									
1900	79	1011	0.36	1.1	4.8	1012	827								
2000	80	1011	0.36	1.1	4.8	1014	825	72.8	23.8	2.1	[illegible]	4.78	89.2	24.5	105.6
2100	81	1011	0.36	1.1	4.8	1010	824								
2200	82	1011	0.36	1.1	4.8	1011									
2300	83	1011	0.36	1.1	4.8	1008	842								
2400	84	1011	0.36	1.1	4.8	1010									
5/13/77															
0100	85	1011	0.36	1.1	4.8	1012	841	76.6	19.9	1.9	1.6	6.84	109.1	35.1	76.6
[illegible]	86	1011	0.36	1.1	4.8	964									
[illegible]	87	1011	0.36	1.1	4.8	971	777								
[illegible]	88	1011	0.36	1.1	4.8	974	771	83.9	13.0	1.6	[illegible]	9.32	173.7	47.8	83.9
[illegible]	89	1011	0.36	1.1	4.8	972	770								
[illegible]	90	1011	0.36	1.1	4.8	968									

TABLE 5-1

Time	Scan No.	Space Velocity in HR^{-1}	Flow Rate		Molar Ratio of Steam to Carbon S/C	Temperature		Volumetric Produce Gas Compn. % (Dry Basis)				$\frac{CH_4}{CO+CO_2+CH_4}$ %	$\frac{H_2}{3(CO+CO_2+CH_4)}$ %	$\frac{CH_4}{\cdot 1949\,(CO+CO_2+CH_4)}$ %	$\frac{C_{out}}{C_{in}} \times 100$
		Input (Fuel/Water)	Fuel in Lbs/hr	Water in Lbs/hr		Preheat ^oF	Bed Exit ^oF	H_2	CO_2	CO	CH_4				
0700	91	1011	0.36	1.1	4.8	975	772								
0800	92	1011	0.36	1.1	4.8	973	780	79.8	16.8	1.7	1.8	8.87	131.0	45.5	79.8
0900	93	1011	0.36	1.1	4.8	970	786								
1000	94	1011	0.36	1.1	4.8	971	777								
1100	95	1011	0.36	1.1	4.8	968	783	73.2	24.	1.3	1.5	5.6	91.1	28.7	99.7
1200	96	1011	0.36	1.1	4.8	969	781								
1300	97	1011	0.36	1.1	4.8	970	783								
1400	98	1011	0.36	1.1	4.8	977	787								
1500	99	1011	0.36	1.1	4.8	979	788								
1600	100	1011	0.36	1.1	4.8	978	781	73.6	23.6	1.3	1.5	5.7	92.9	29.2	93.9
1700	101	774	0.4	1.1	4.3	979									
1800	102	1007	0.35	0.78	3.5		778	74.7	33	1.4	1.8	7.2	98.7	9.2	77.8

STEAM REFORMING OF METHANOL/ GASOLINE (90/10 BY WT.)

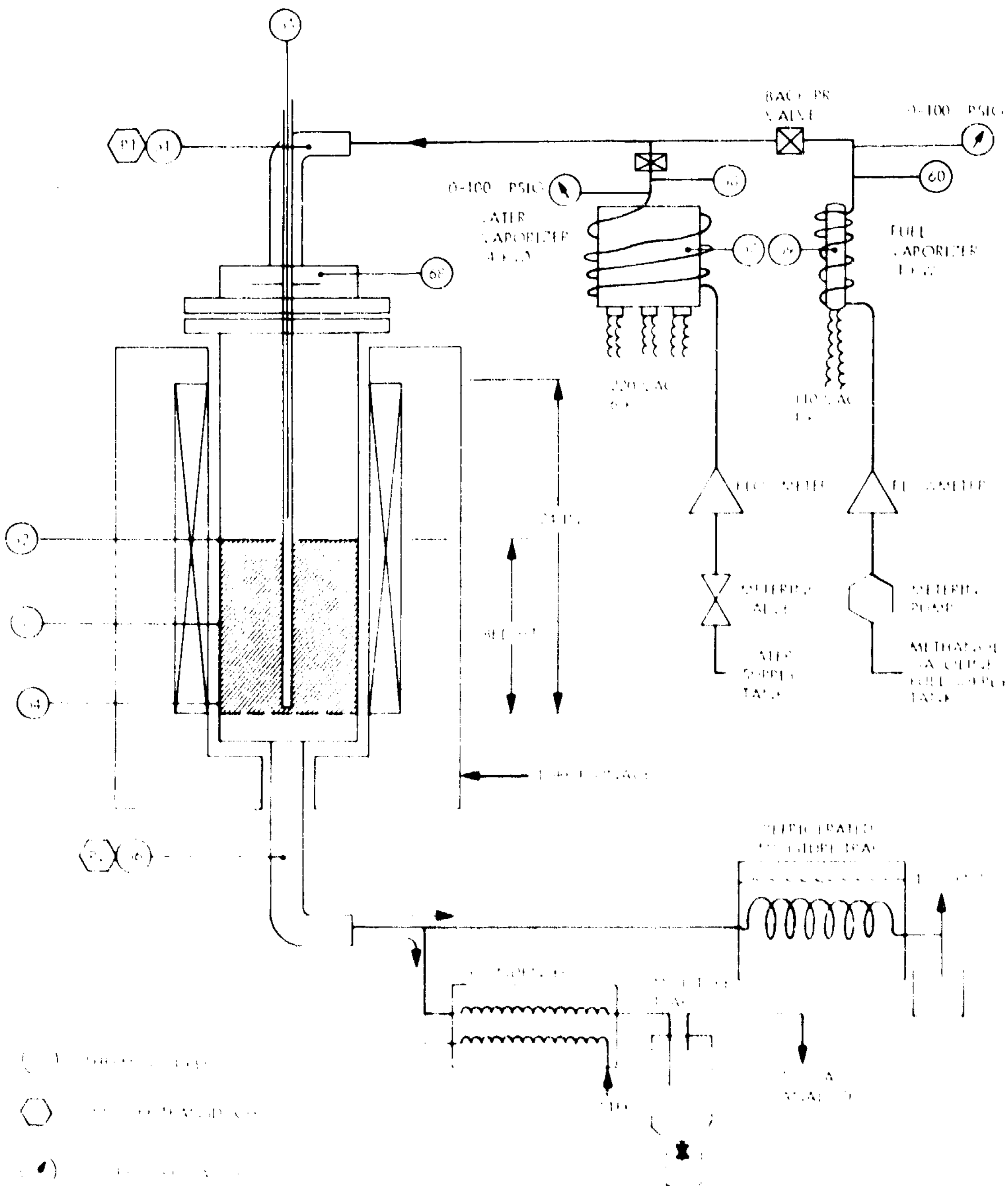


Figure 2-1 Schematic of Steam Reformer

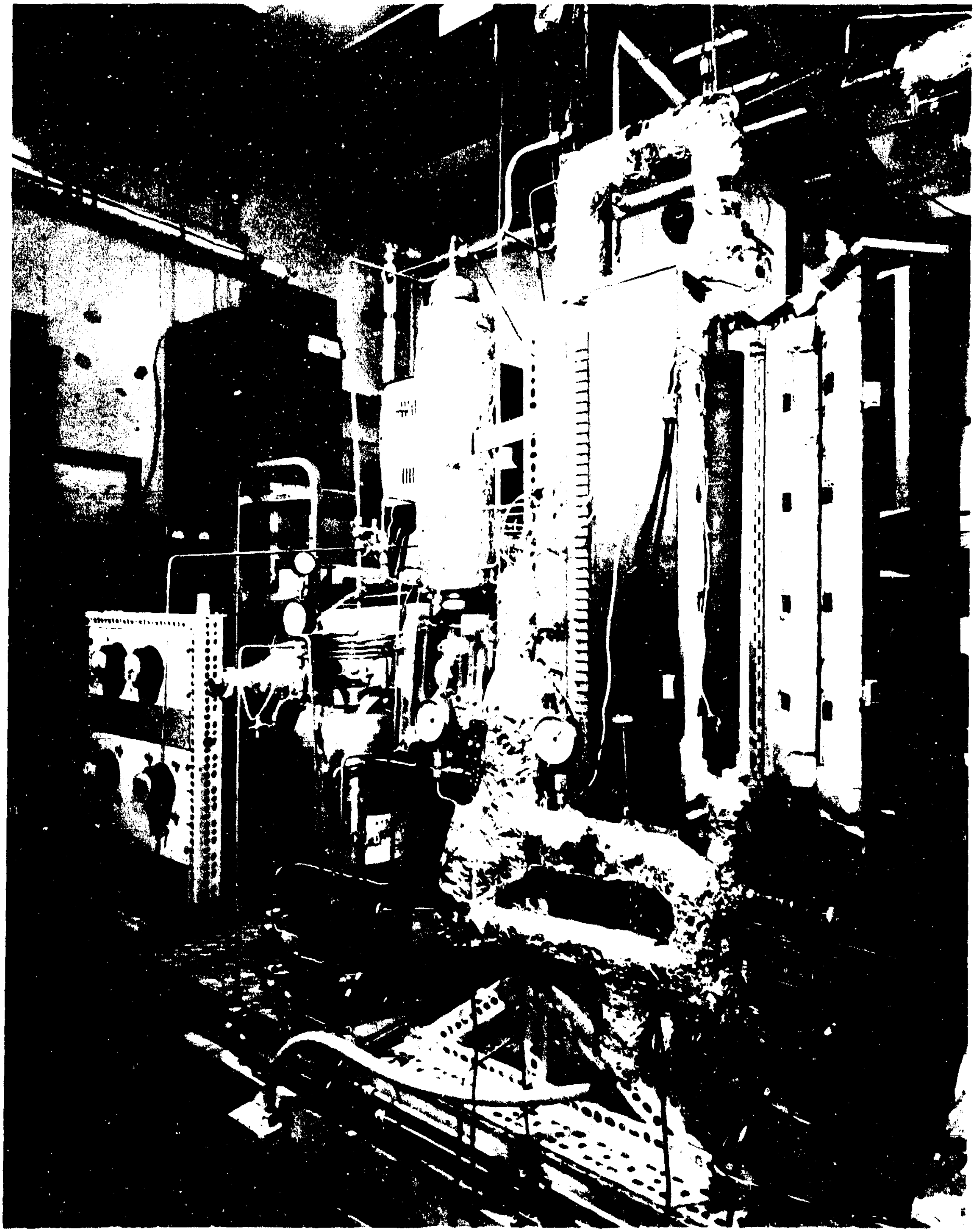


Figure 2-2 Photographic View
of Steam Reforming System

STEAM REFORMING OF METHANOL/GASOLINE (90/10 BY WT.)

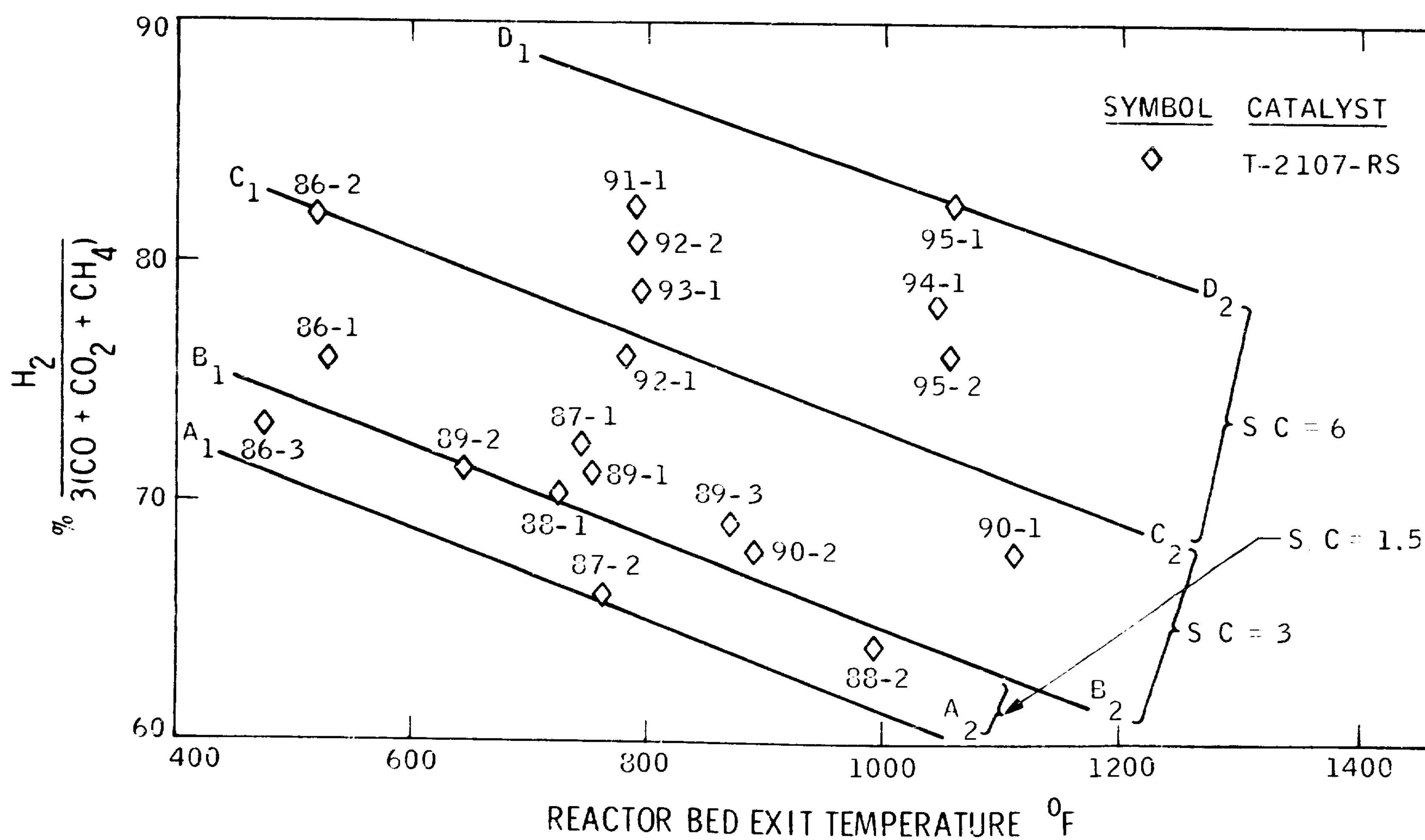


Figure 4-1 Effect of Reactor Bed Temperature on Hydrogen Yield

STEAM REFORMING OF METHANOL/GASOLINE (90/10 BY WT.)

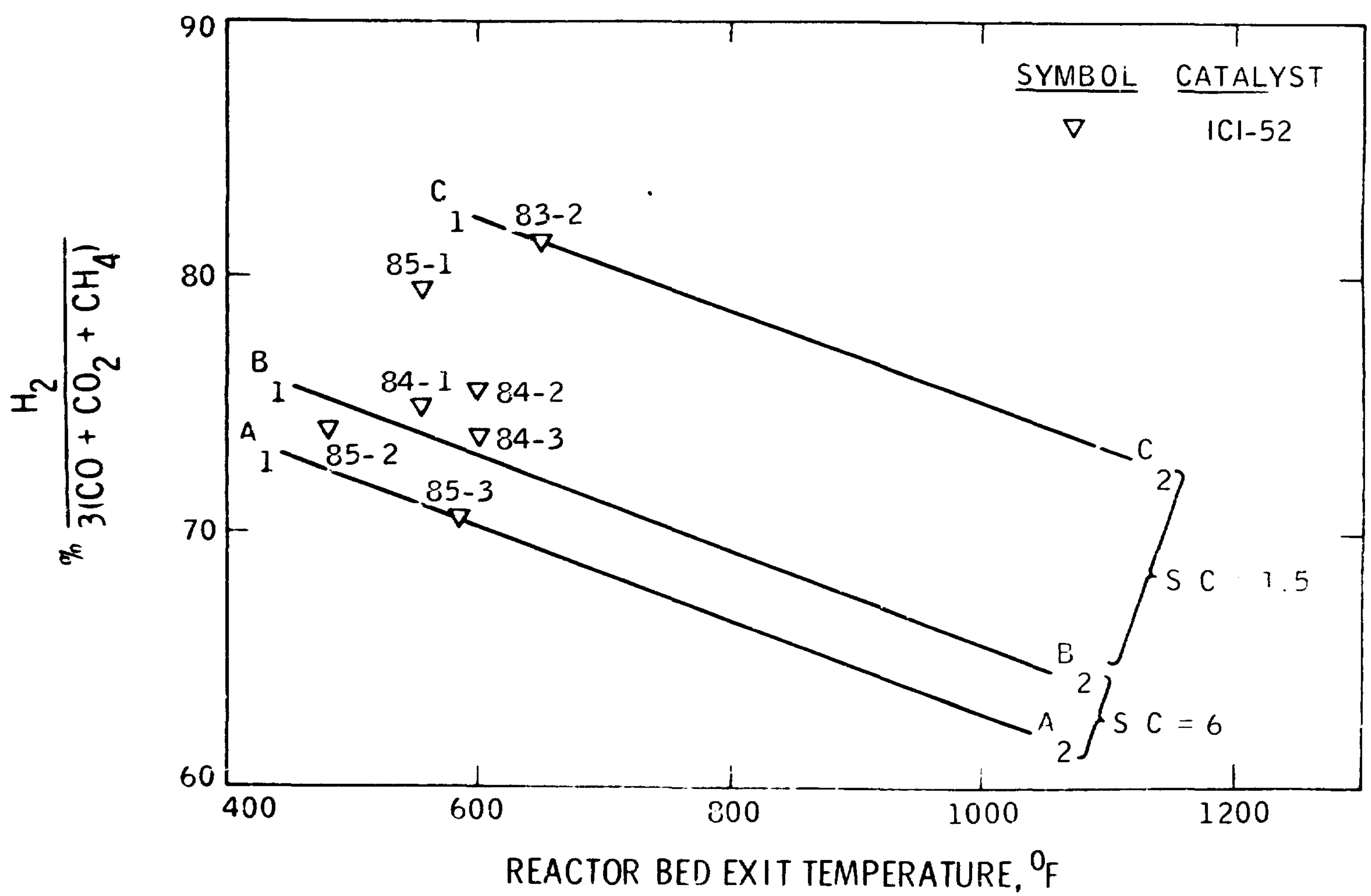


Figure 4-2 Effect of Reactor Bed Temperature on Hydrogen Yield

STEAM REFORMING OF METHANOL/GASOLINE (90/10 BY WT.)

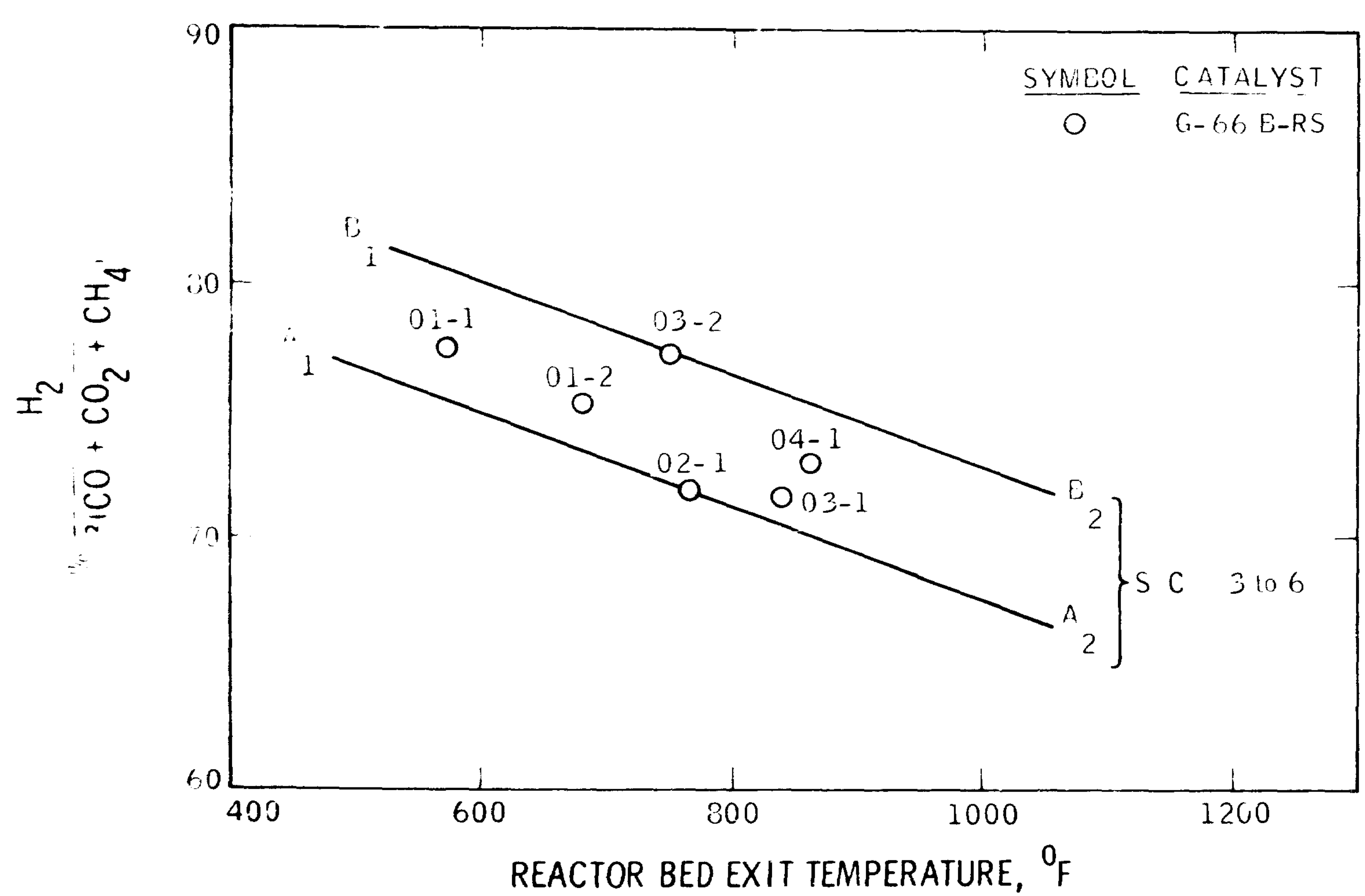


Figure 4-3 Effect of Reactor Bed Temperature on Hydrogen Yield

STEAM REFORMING OF METHANOL/GASOLINE (90/10 BY WT.)

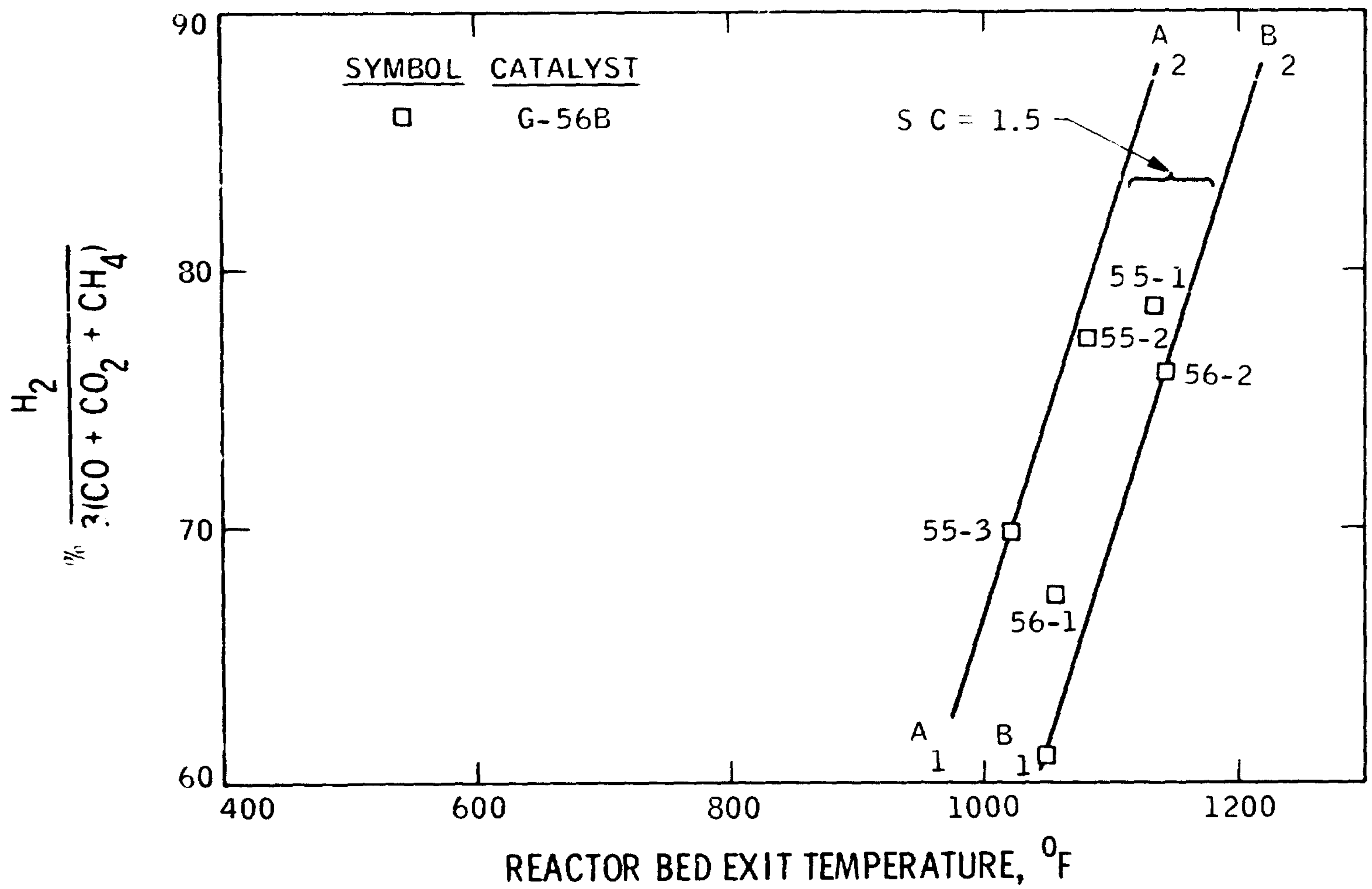


Figure 4-4 Effect of Reactor Bed Temperature on Hydrogen Yield

STEAM REFORMING OF METHANOL/GASOLINE (90/10 BY WT.)

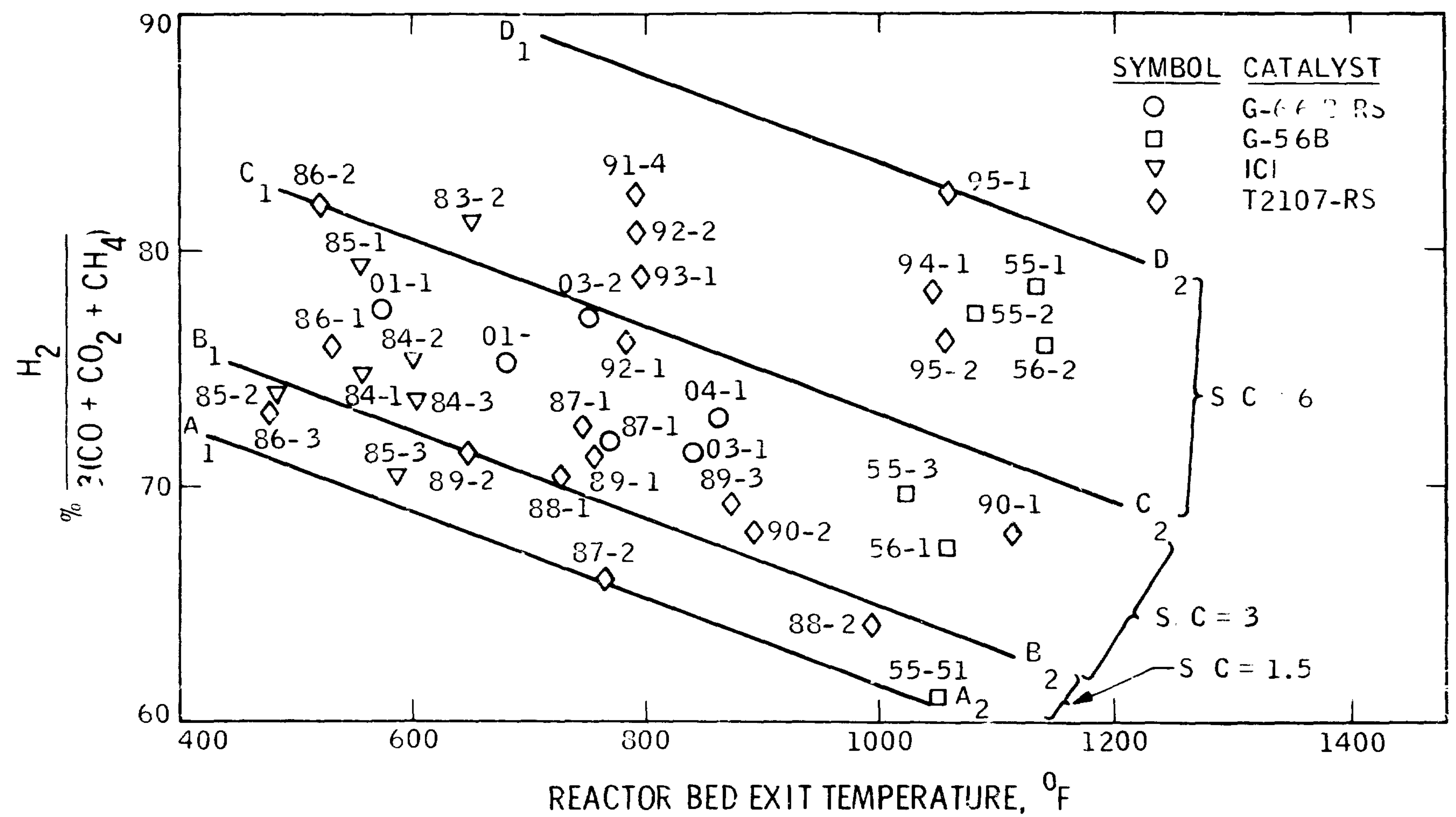


Figure 4-5 Effect of Reactor Bed Temperature on Hydrogen Yield

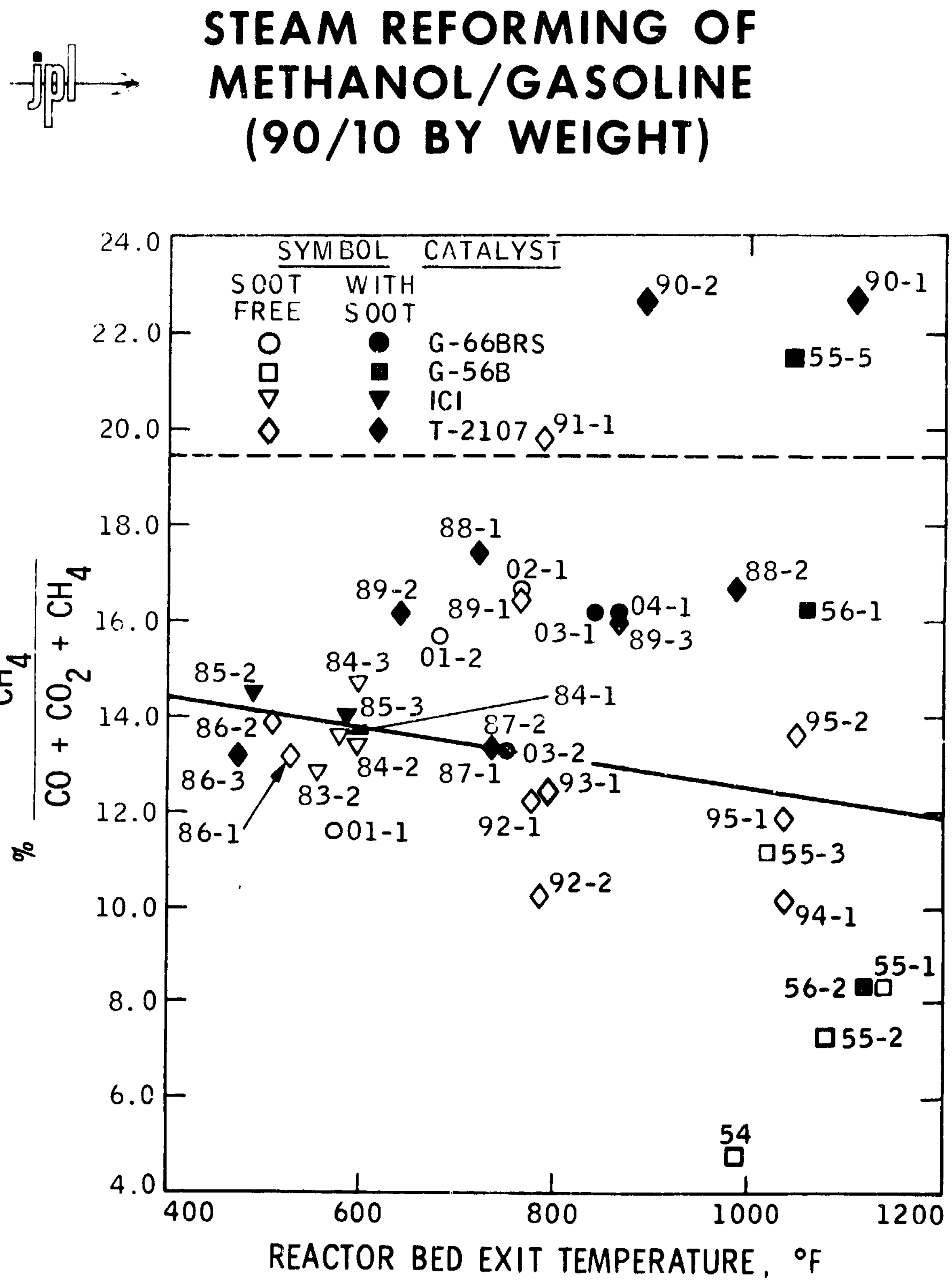


Figure 4-6 Effect of Reactor Bed Temperature on Gaseous Hydrocarbons

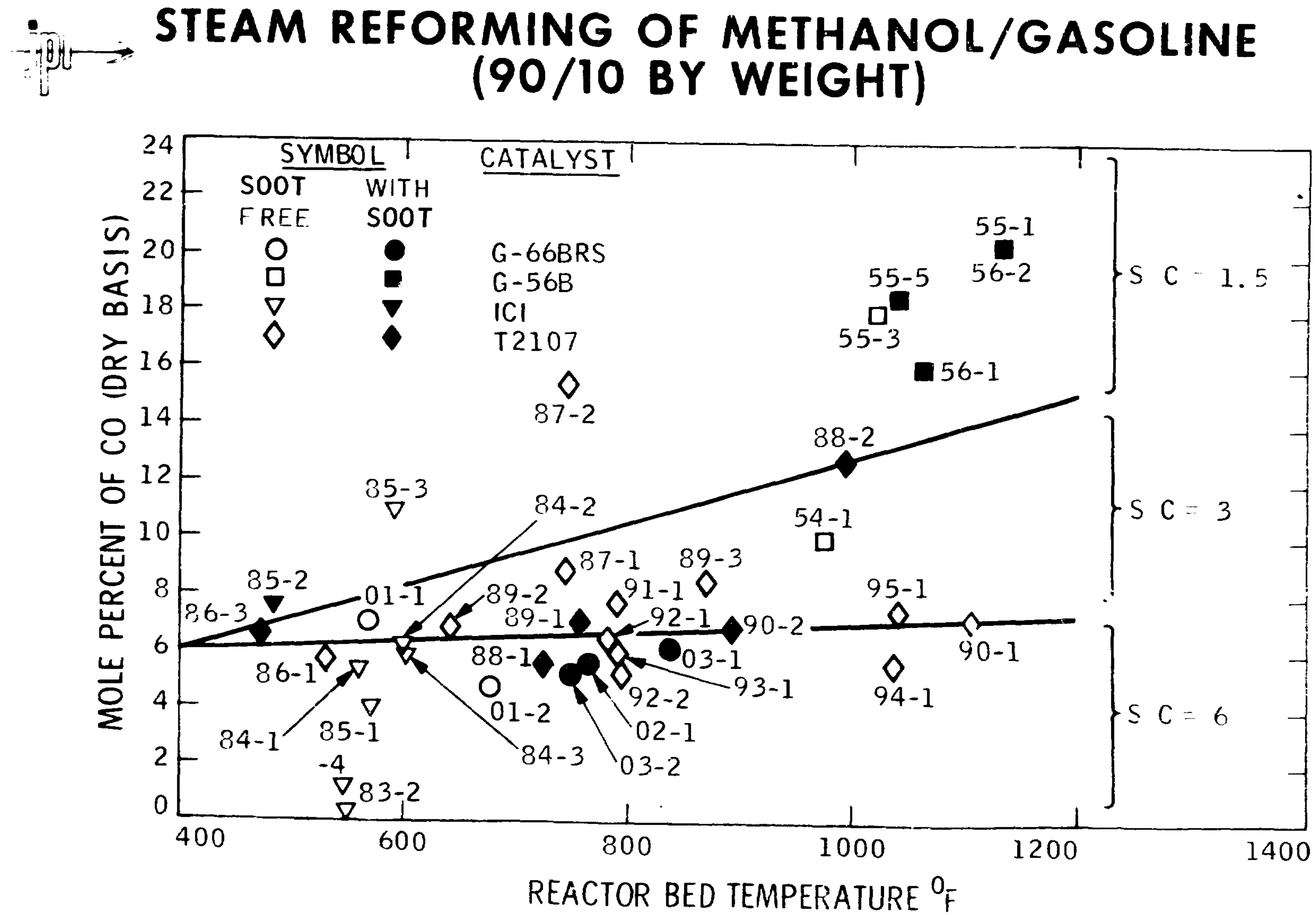


Figure 4-7 Carbon Dioxide Concentration (Dry Basis) During Process Parametric Study Tests

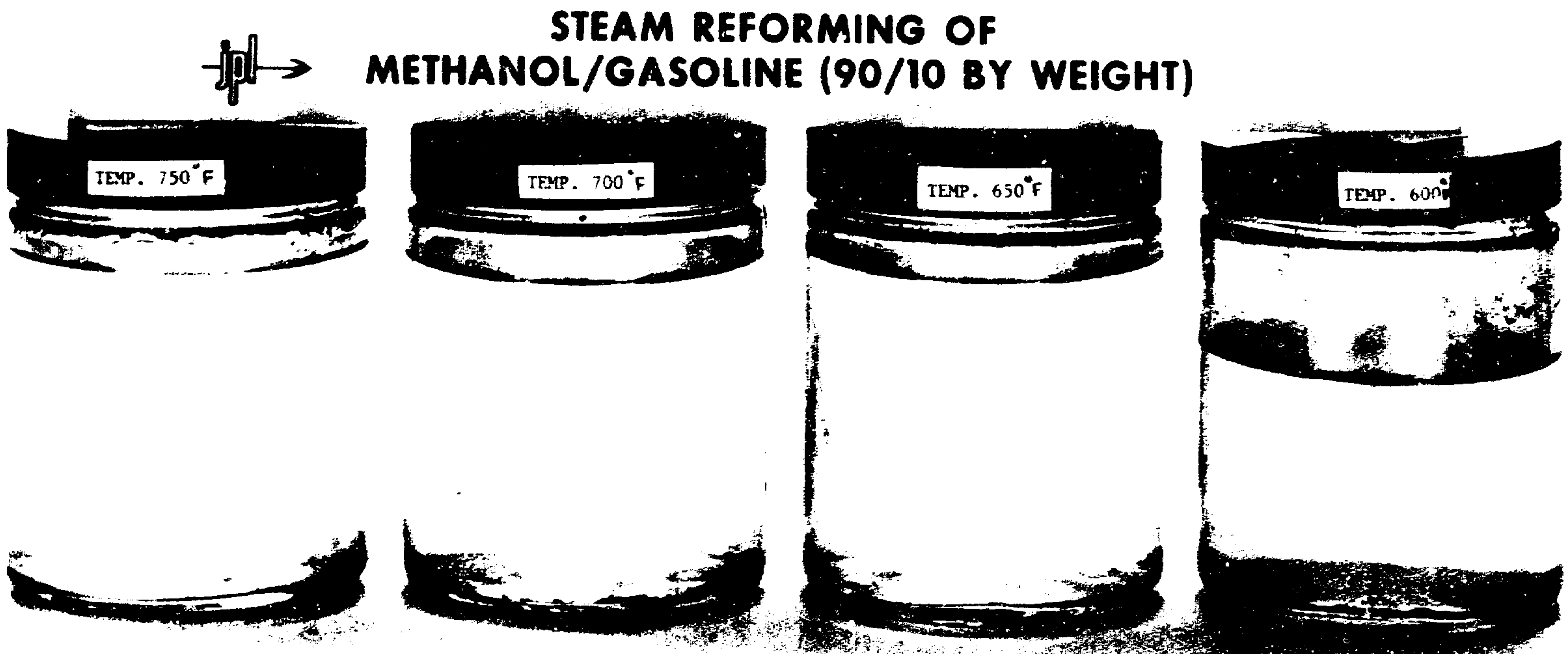


Figure 4-[illegible] Effect of Reactor Bed Temperature on Liquid Hydrocarbons in Condensate Samples.

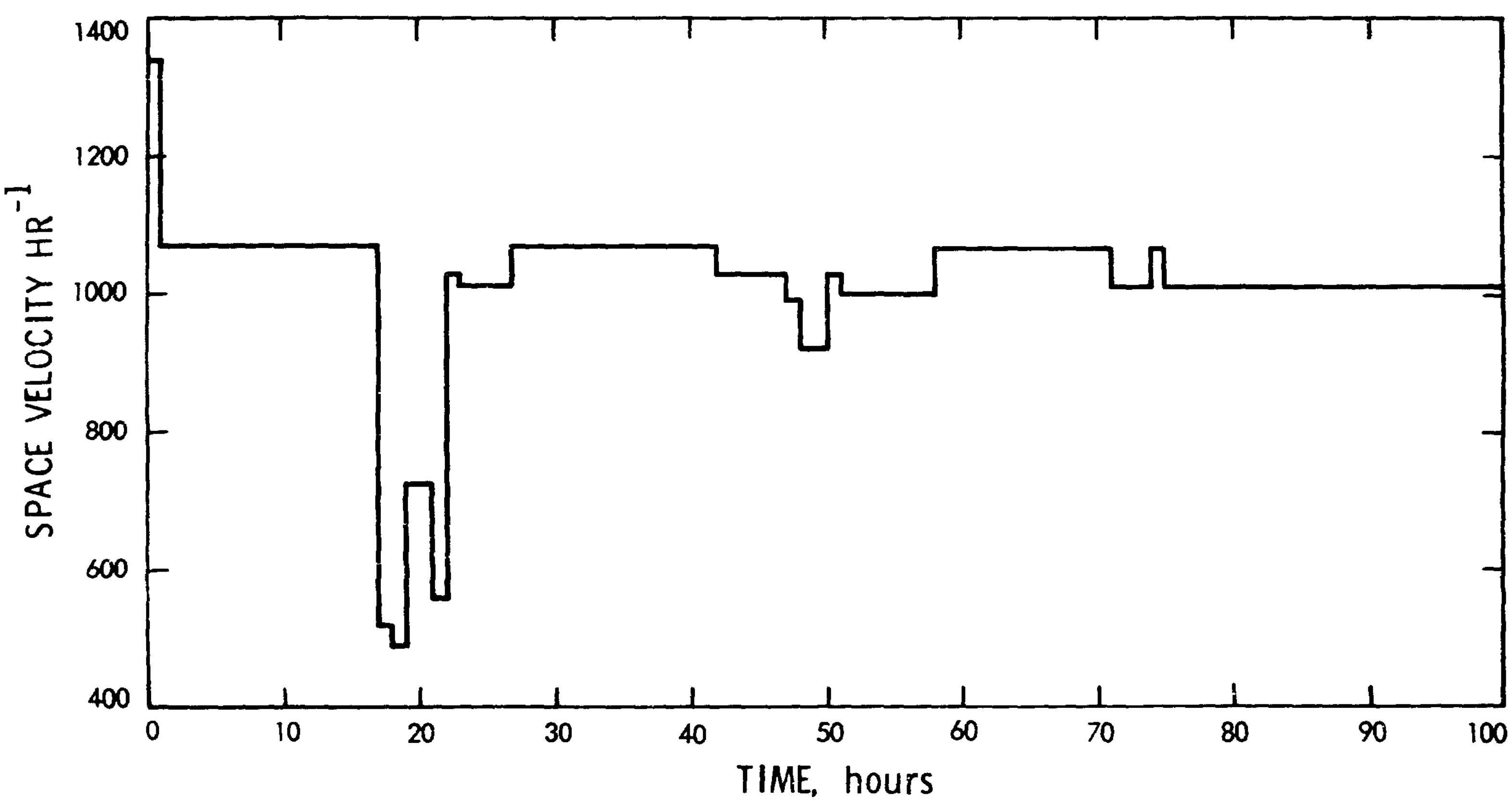


Figure 5-1 Variation in Space
Velocity in 100 Hour Test

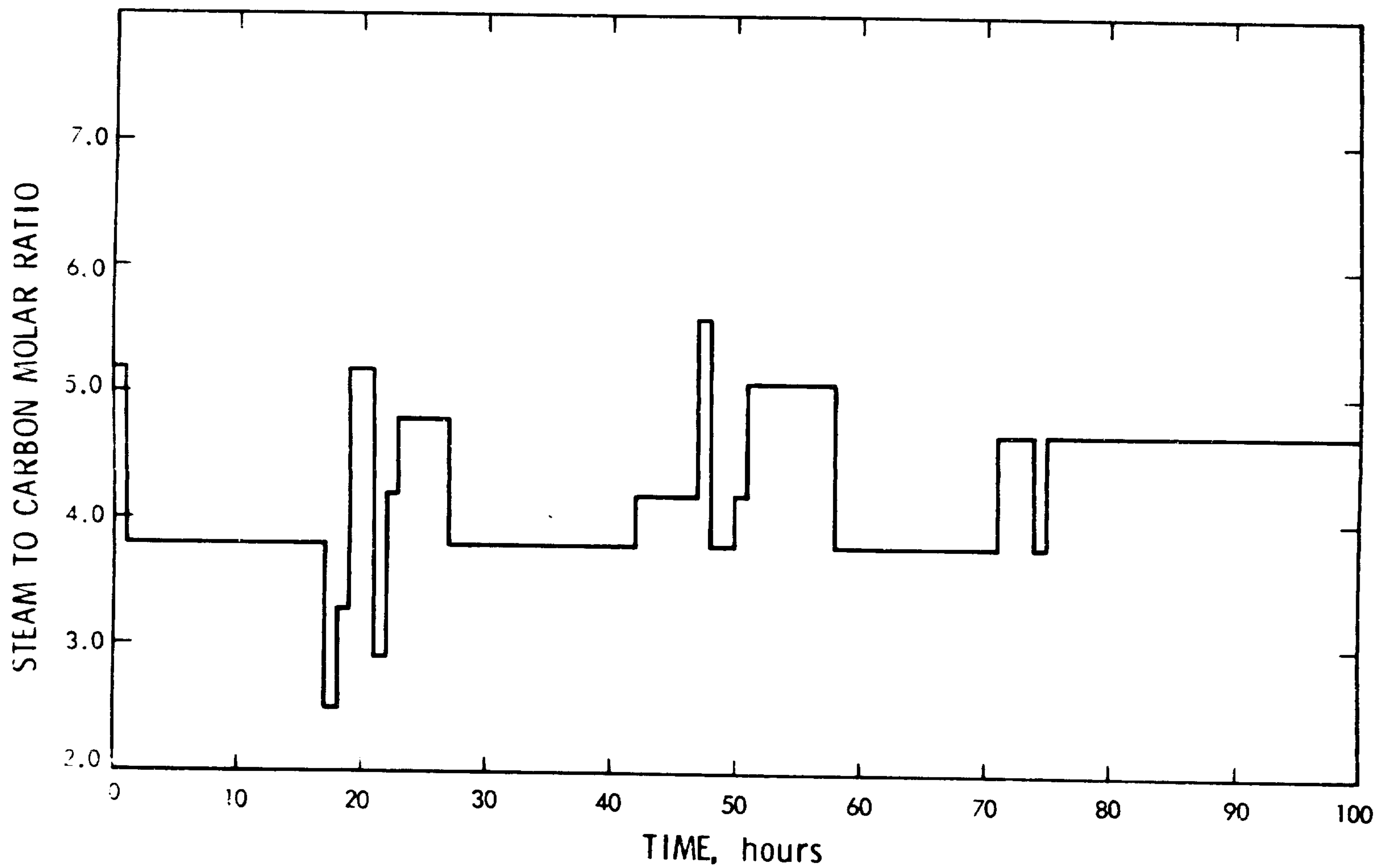


Figure 5-2 Variation in Steam to Carbon Molar Ratio in 100 Hour Test

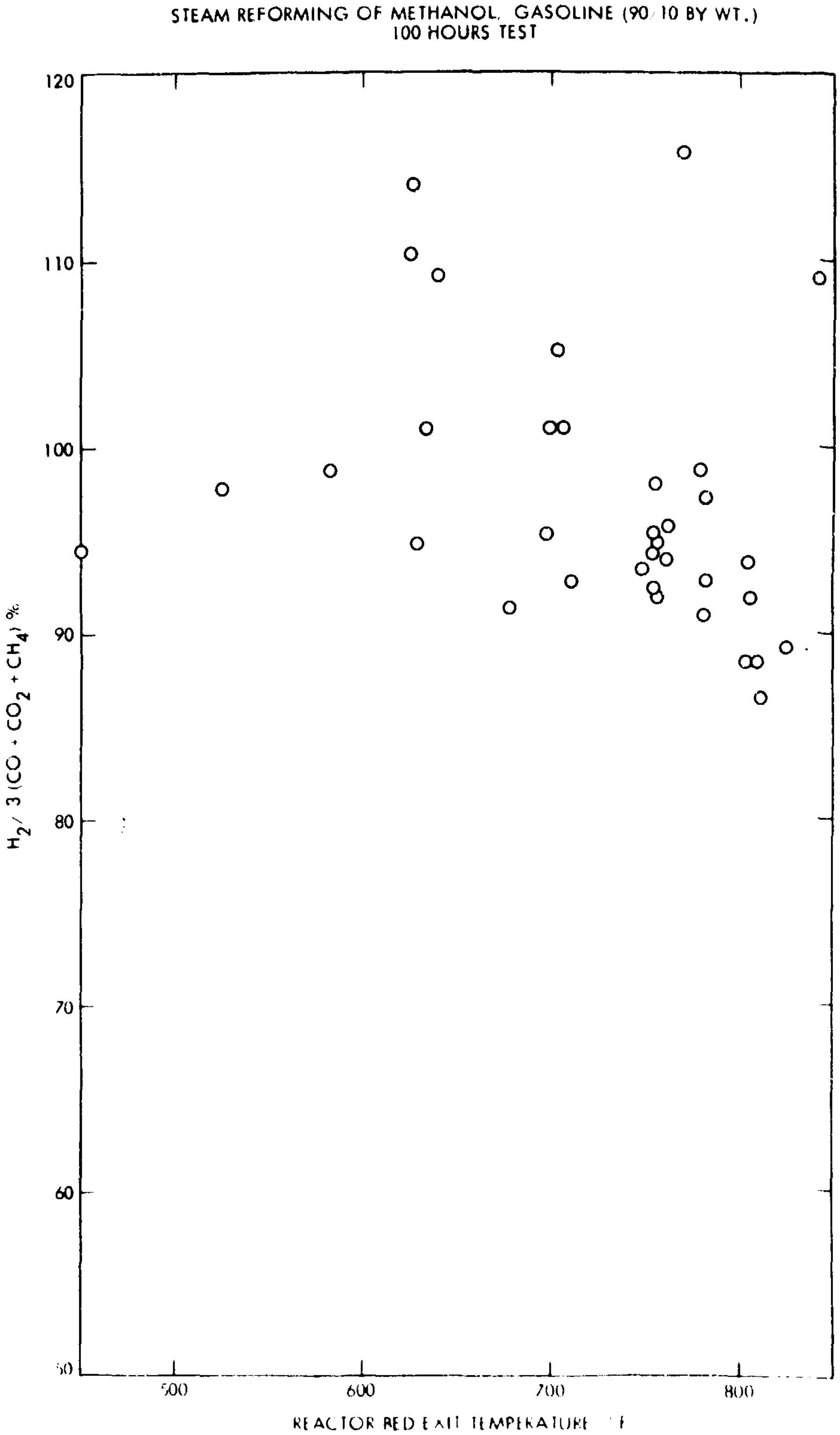


Figure 5-3 Effect of Reactor Bed Temperature on Hydrogen Yield

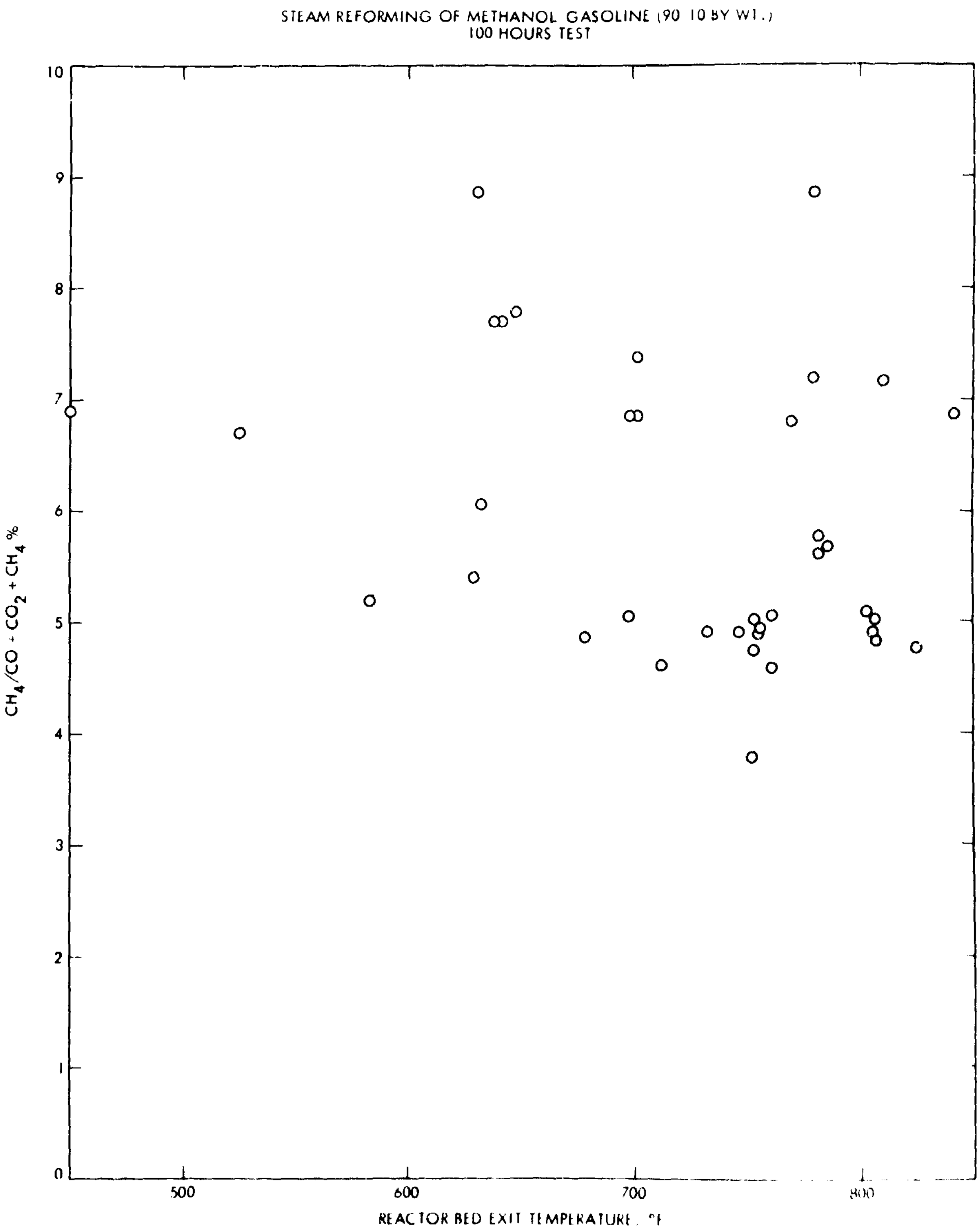


Figure 5-4 Effect of Reactor Bed Exit Temperature on Gaseous Hydrocarbons

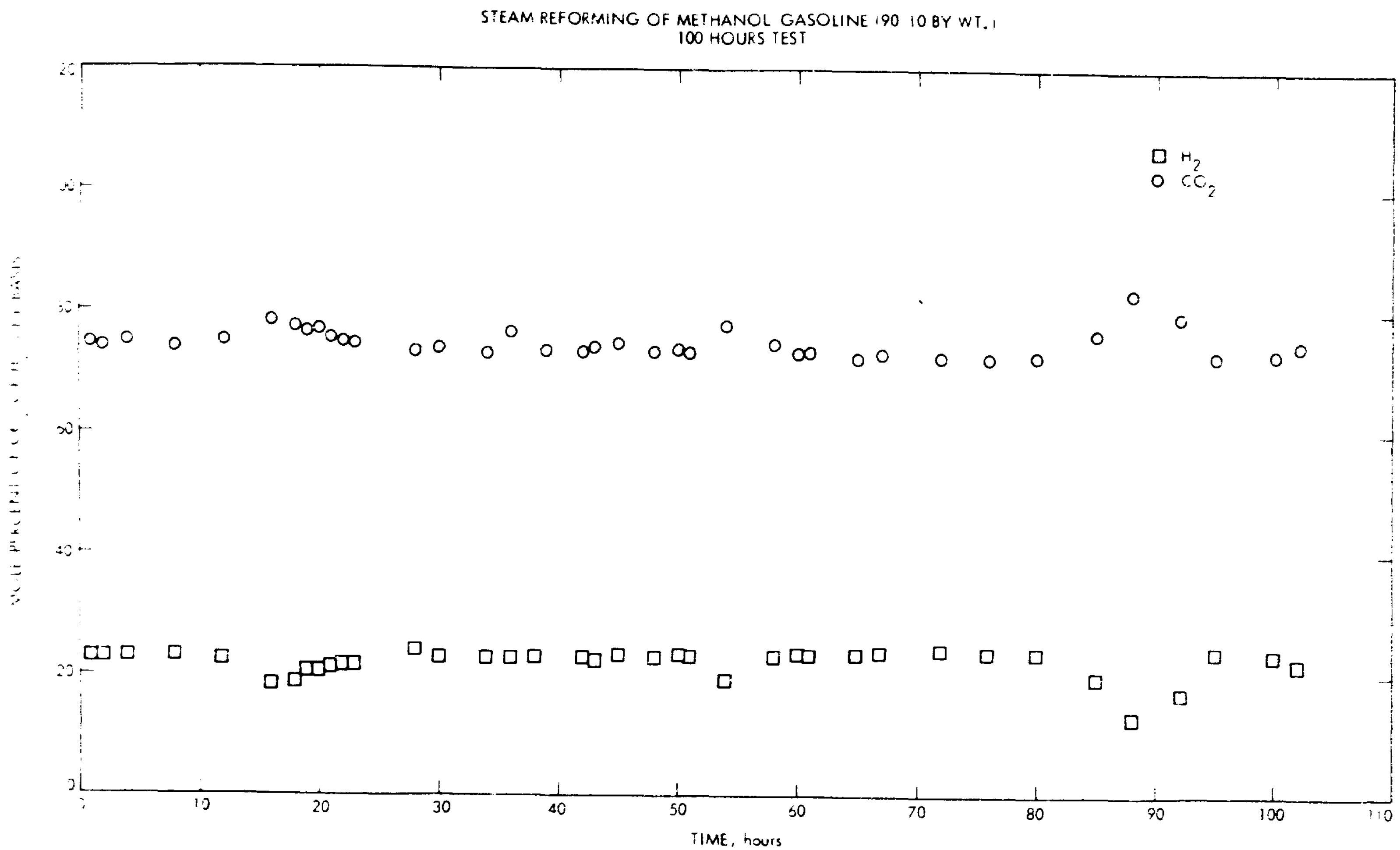


Figure 5-5 Carbon Dioxide and Hydrogen Concentration (Dry Basis) During 100 Hour Test

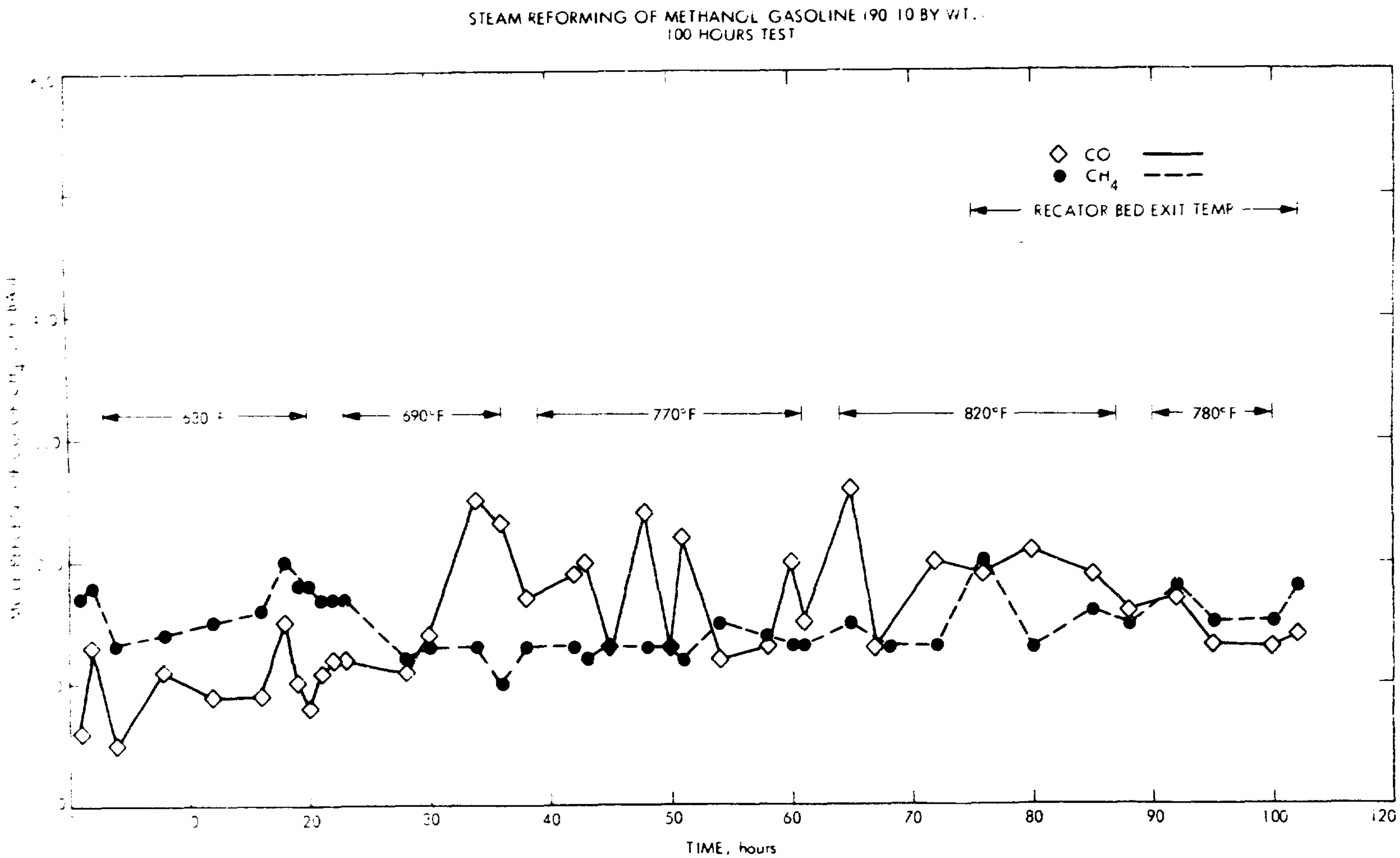


Figure 5-6 Carbon Monoxide and Methane Concentration (Dry Basis) During 100 Hour Test

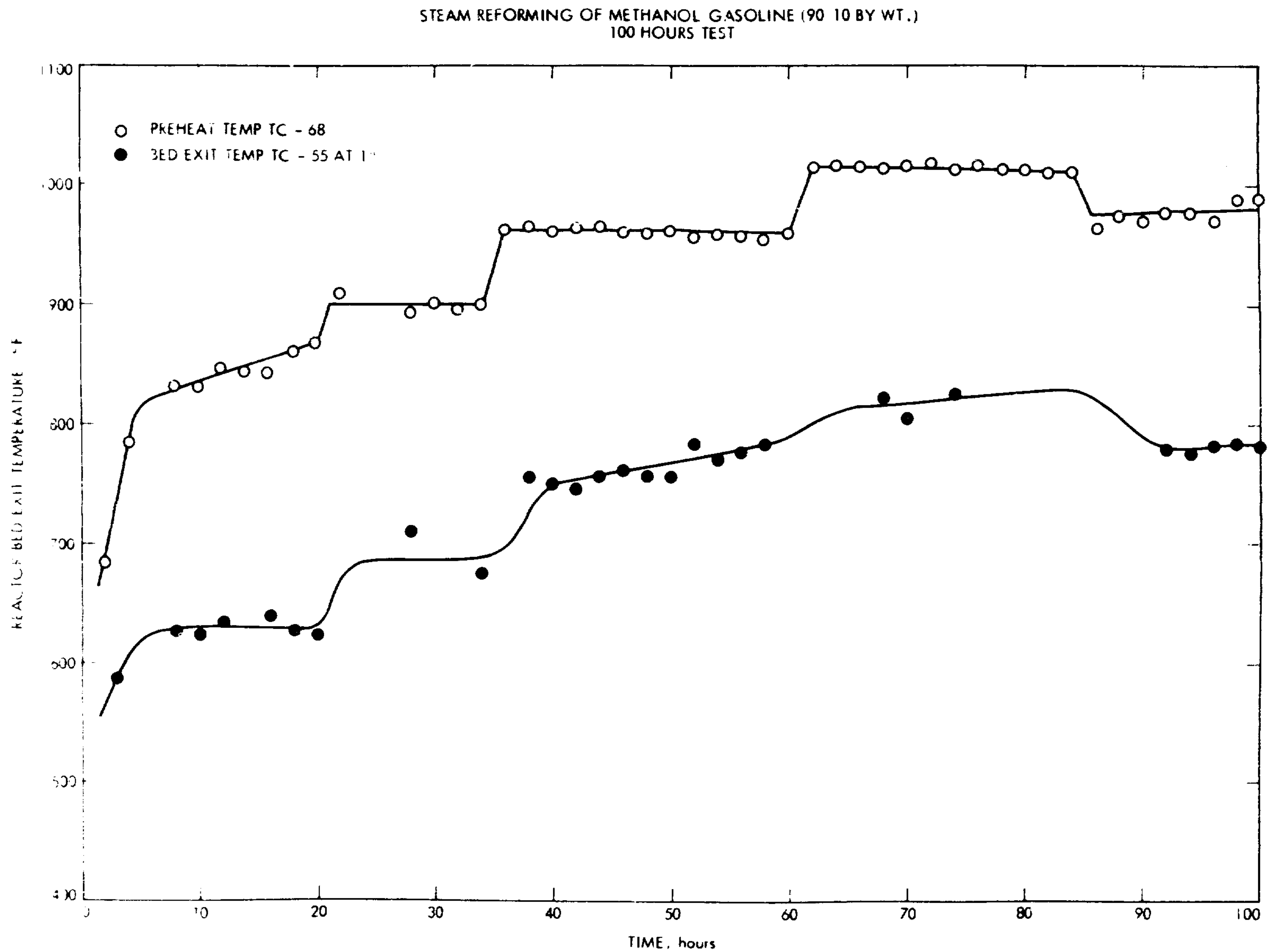


Figure 5-7 Bed Exit and Gas-Pre-
heat Temperatures in 100 Hour Test

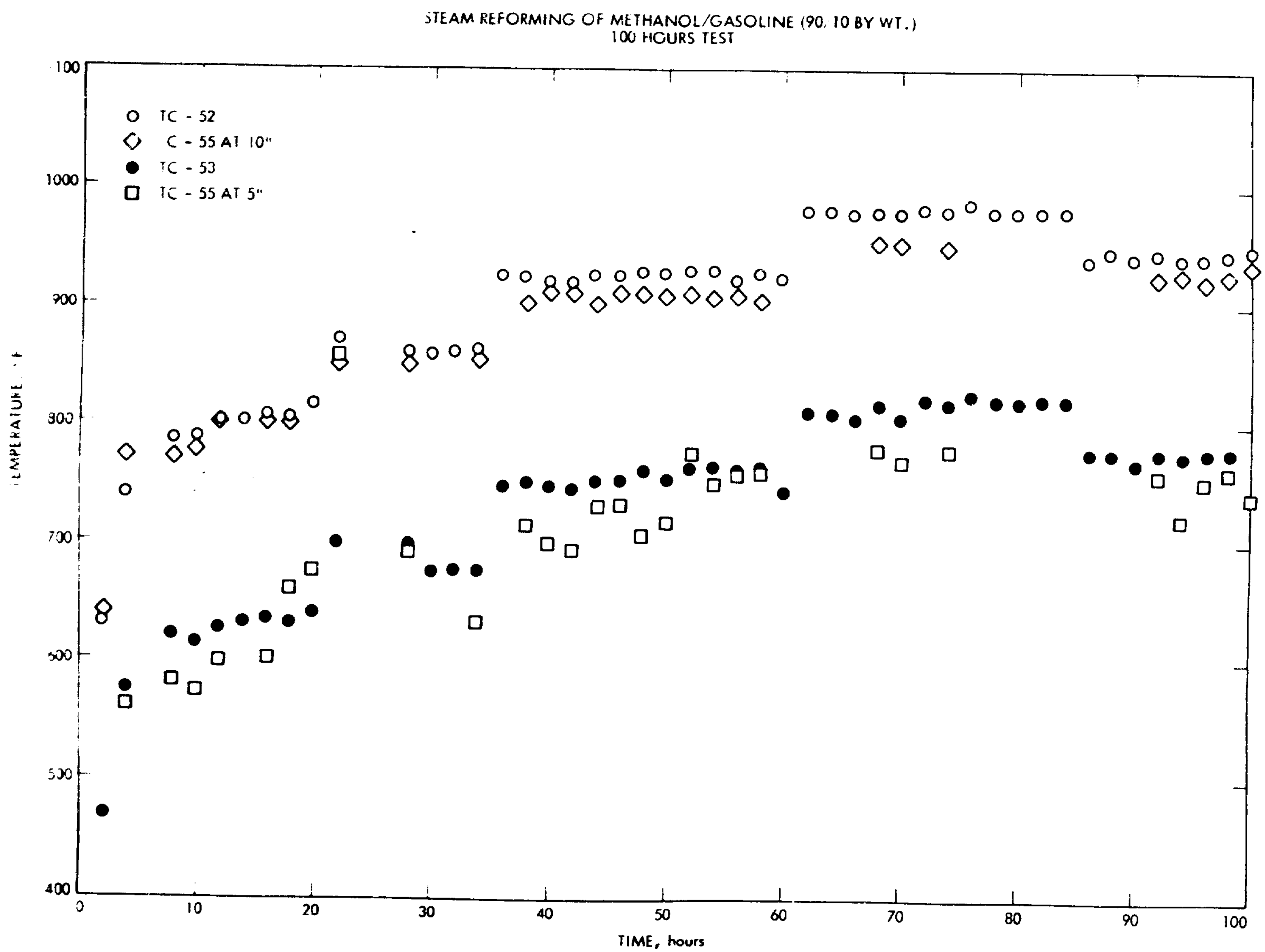


Figure 5-8 Reactor Bed and Reactor Wall Temperature Profile in 100 Hour Test

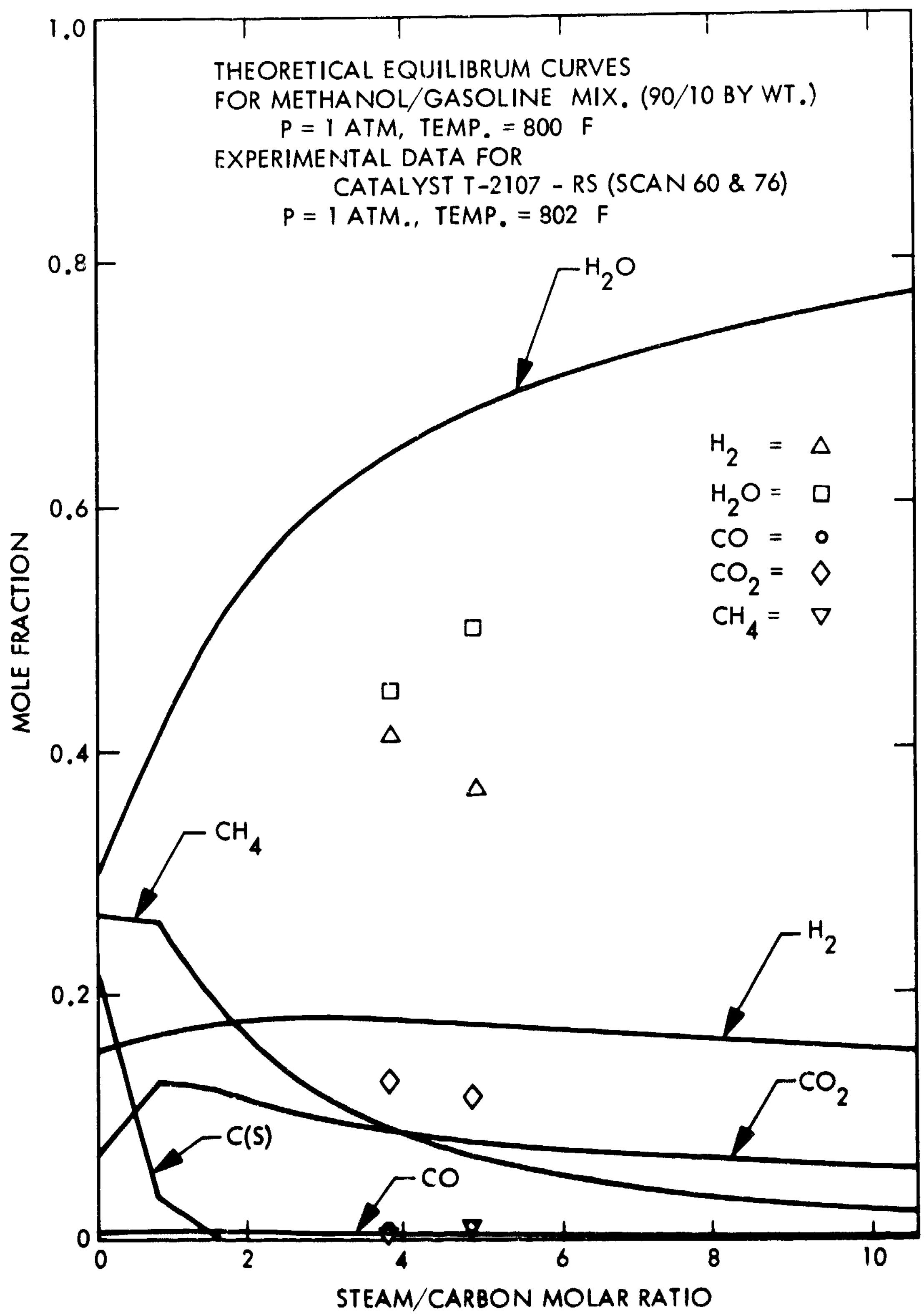


Figure 5-9. Product Distribution

APPENDIX

Equilibrium Product Composition of Methyl Fuel

APPENDIX

EQUILIBRIUM PRODUCT COMPOSITION OF METHYL FUEL

The equilibrium product compositions of 90/10 methanol/gasoline mixtures (by weight) have been calculated with the CEC 71 Computer program. This program is based on the minimization of Gibb's Free Energy of the System. A subprogram has been added to the main program to enable plotting of the equilibrium composition versus the input conditions such as steam to carbon ratio. The results of the program can be used further to calculate the yield in terms of product to fuel carbon molar ratio. The moles of hydrogen plus carbon monoxide produced per mole of fuel carbon input were also calculated. Such normalized data represents a good means for comparing yields.

The ranges of this survey are listed in Table A where the ranges of temperature, pressure, and steam to carbon ratio of the reactants are given.

TABLE A

RANGE OF OPERATING CONDITIONS OF STEAM REFORMING SURVEY

Pressure (atm): 1, 3, 5

Temperature (^{o}F) 400, 600, 800, 1000, 1200, 1400, 1600

Steam to Carbon Molar Ratio: 0-15

The main products at various steam to carbon ratios are given in Figures 1 to 21 in mole fractions and in Tables 1 to 21. In those figures, the unconverted water increases as the steam to carbon ratio increases. Methane decreases as the steam to carbon ratio and temperature increase. Pressure has only a small effect. The hydrogen yield at 400^{o}F is very low. It increases very fast as the temperature is increased. At low temperatures the yield is not sensitive to steam to carbon ratio. As the

temperature increases further, the hydrogen yield reaches a maximum and then gradually decreases. Carbon monoxide decreases with an increase of steam to carbon, because carbon monoxide shifts to hydrogen.

The products can be normalized by expressing them as moles of product per mole of fuel carbon. The results of this calculation are given in Tables 22 to 42 as a function of temperature and pressure. The tables are tabulated in both weight and molar steam to carbon ratios. Those results are also plotted in Figures 22 to 42. The plots show that the normalized hydrogen plus carbon monoxide yield, reaches a plateau around a steam to carbon ratio of 2. This means that the maximum hydrogen yield can not be increased beyond a steam to carbon ratio of 2. The physical explanation of this fact that after the steam to carbon molar ratio reaches 2, the increase in hydrogen is only at the expense of a decrease in carbon monoxide. This gives an important reason for not using too much steam, as it requires energy to generate the steam. One must also consider the heat of reaction in this reactor, and express the amount of energy required in terms of mass of fuel that is needed. Sometimes, this energy can be supplied by a source of waste heat.

In other cases a fraction of the total fuel input must be used to produce a heat source. However, the efficiency of utilization of this heat depends on the size of the heat exchangers used etc. This is beyond the scope of this survey.

FIGURE 1.

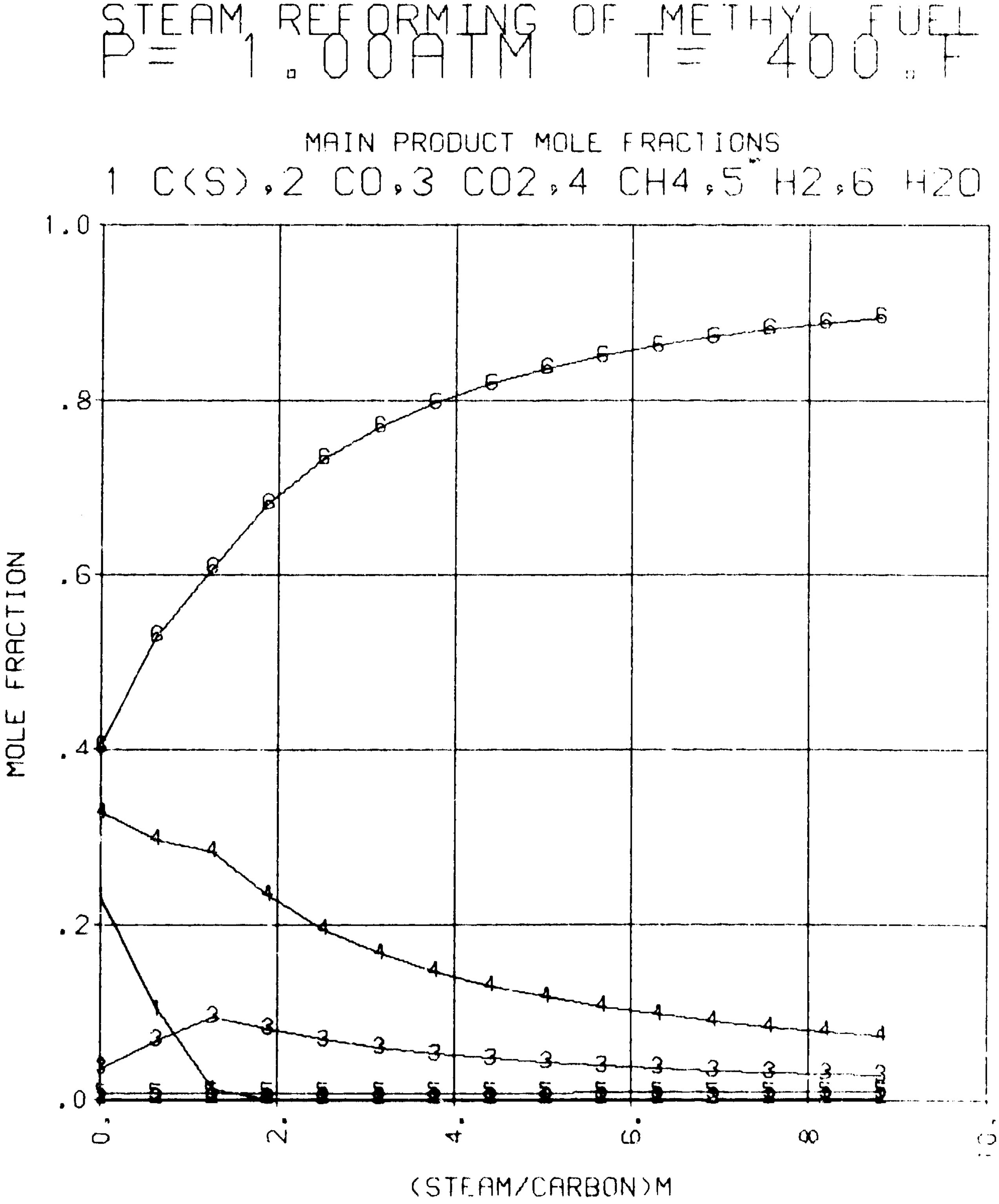

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
(STEAM/CARBON)M

FIGURE 2.

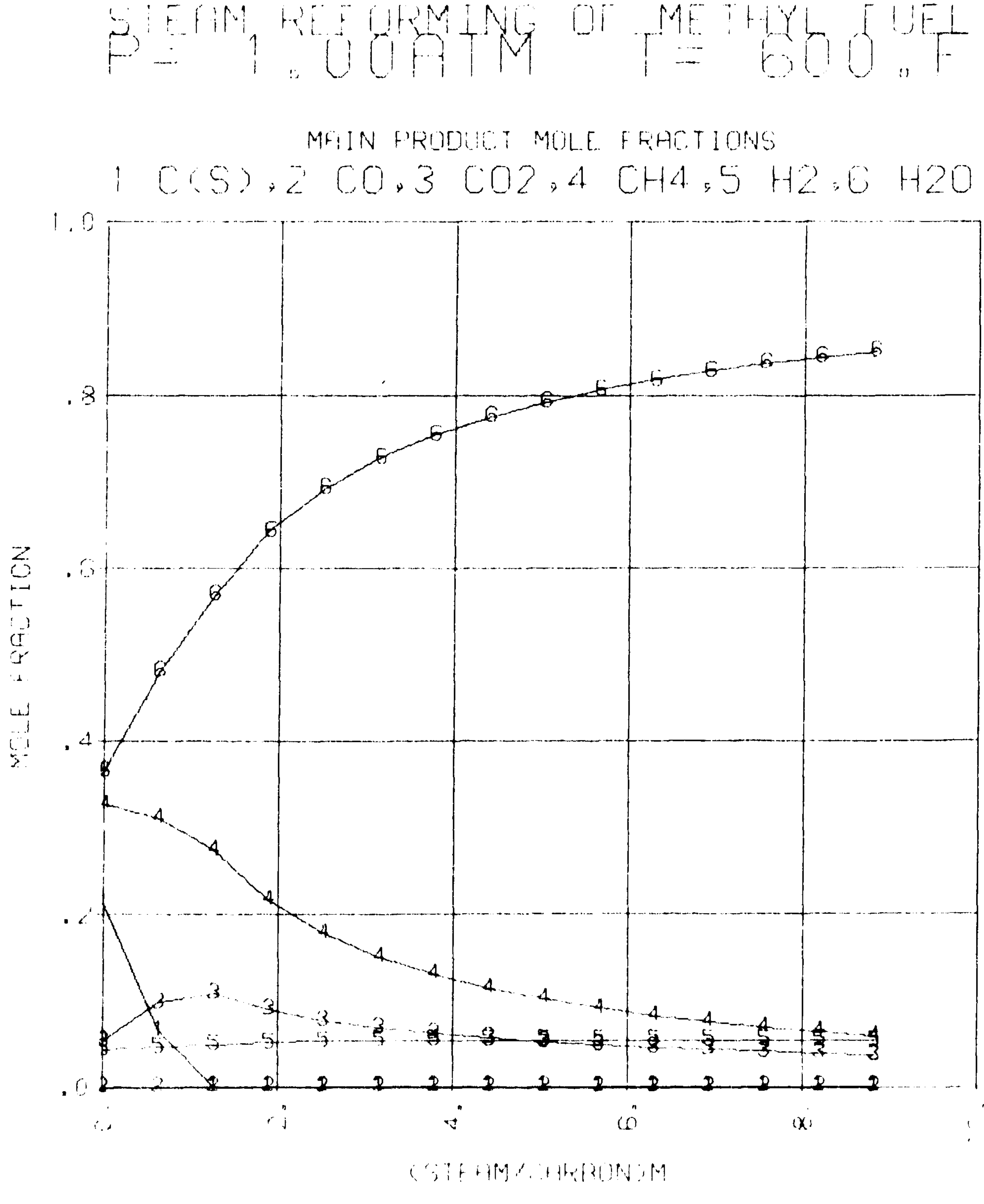
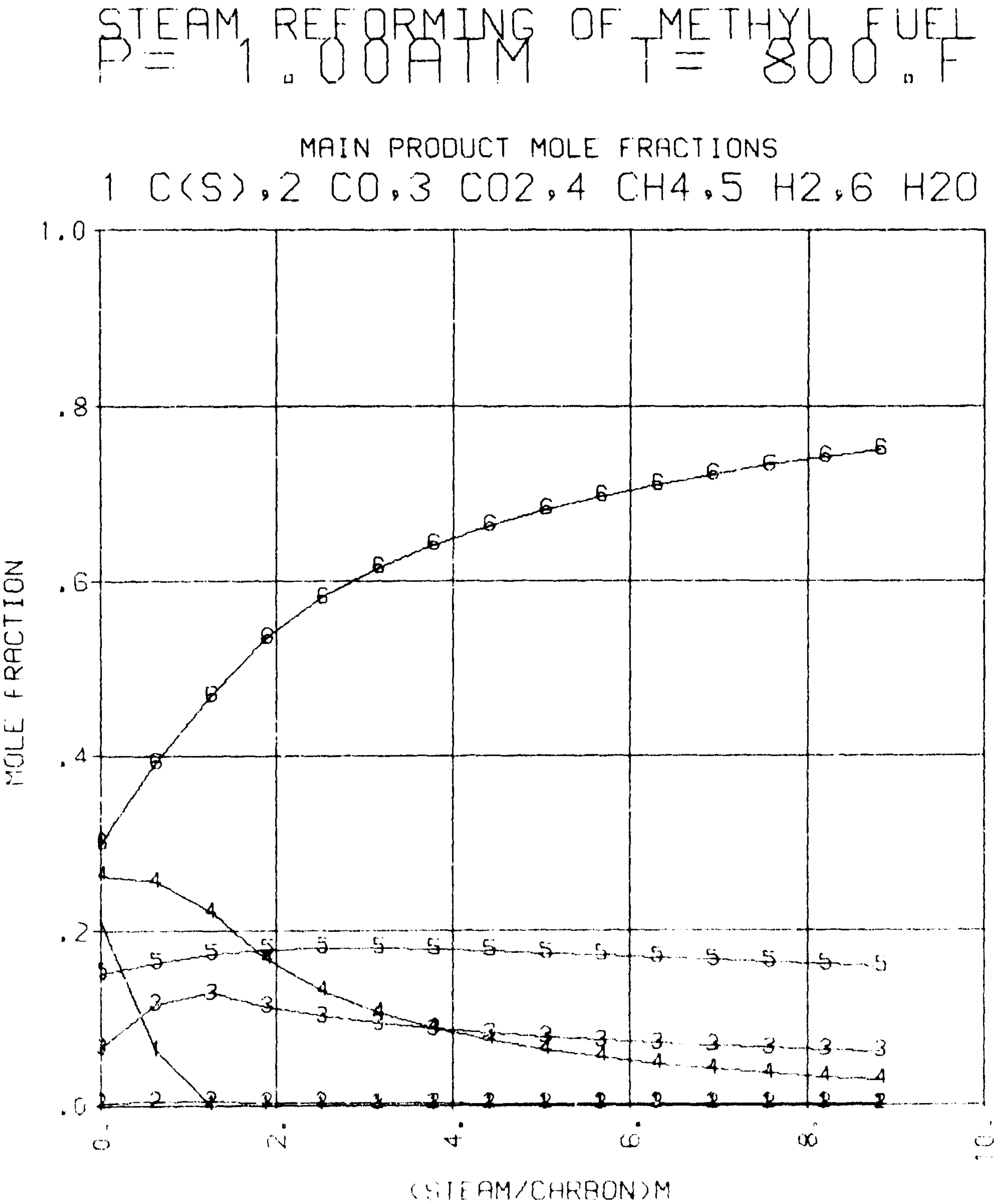
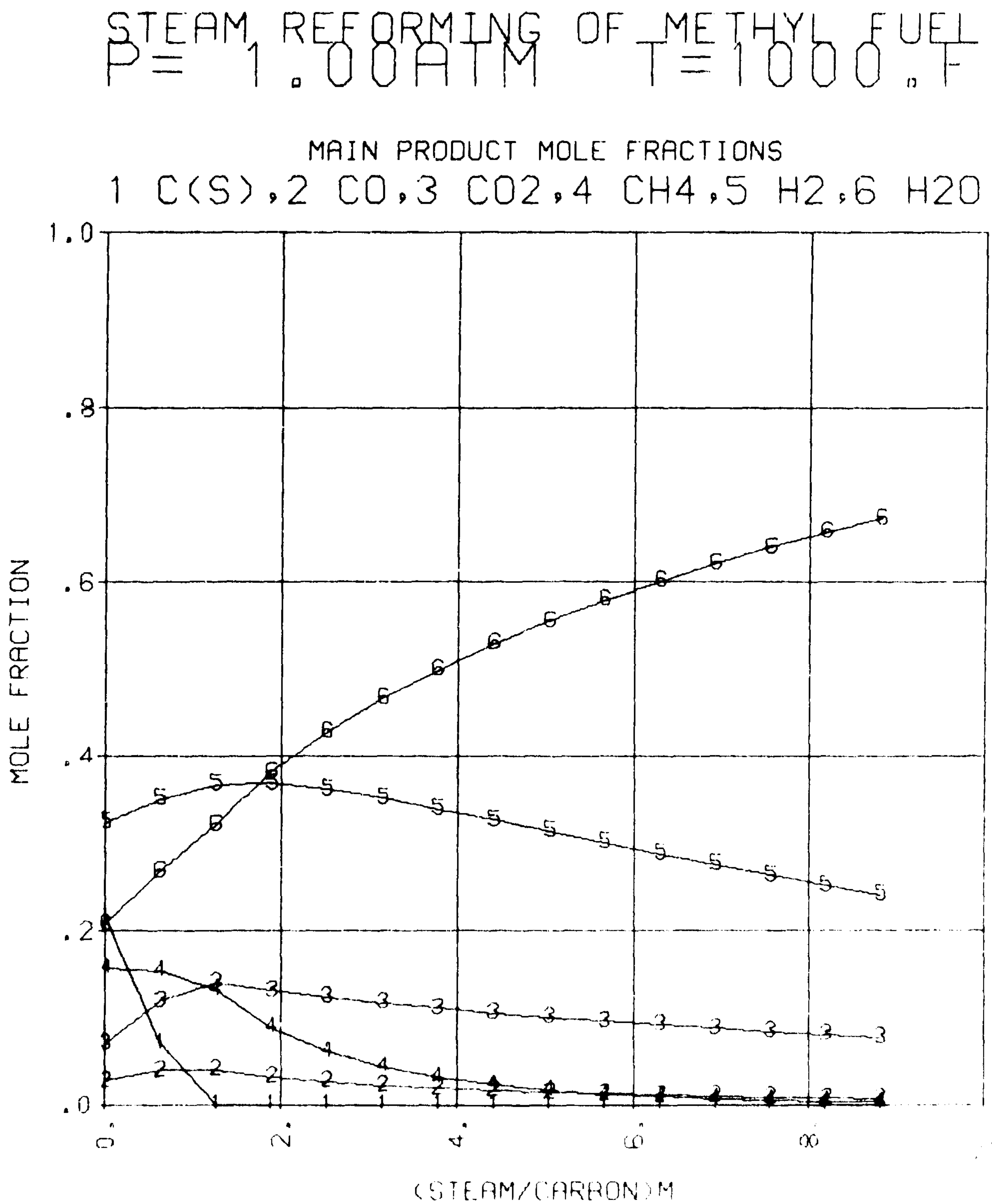

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
(STEAM/CARBON)M
1.0
.8
.6
.4
.2
.0
0
2
4
6
8

FIGURE 3.



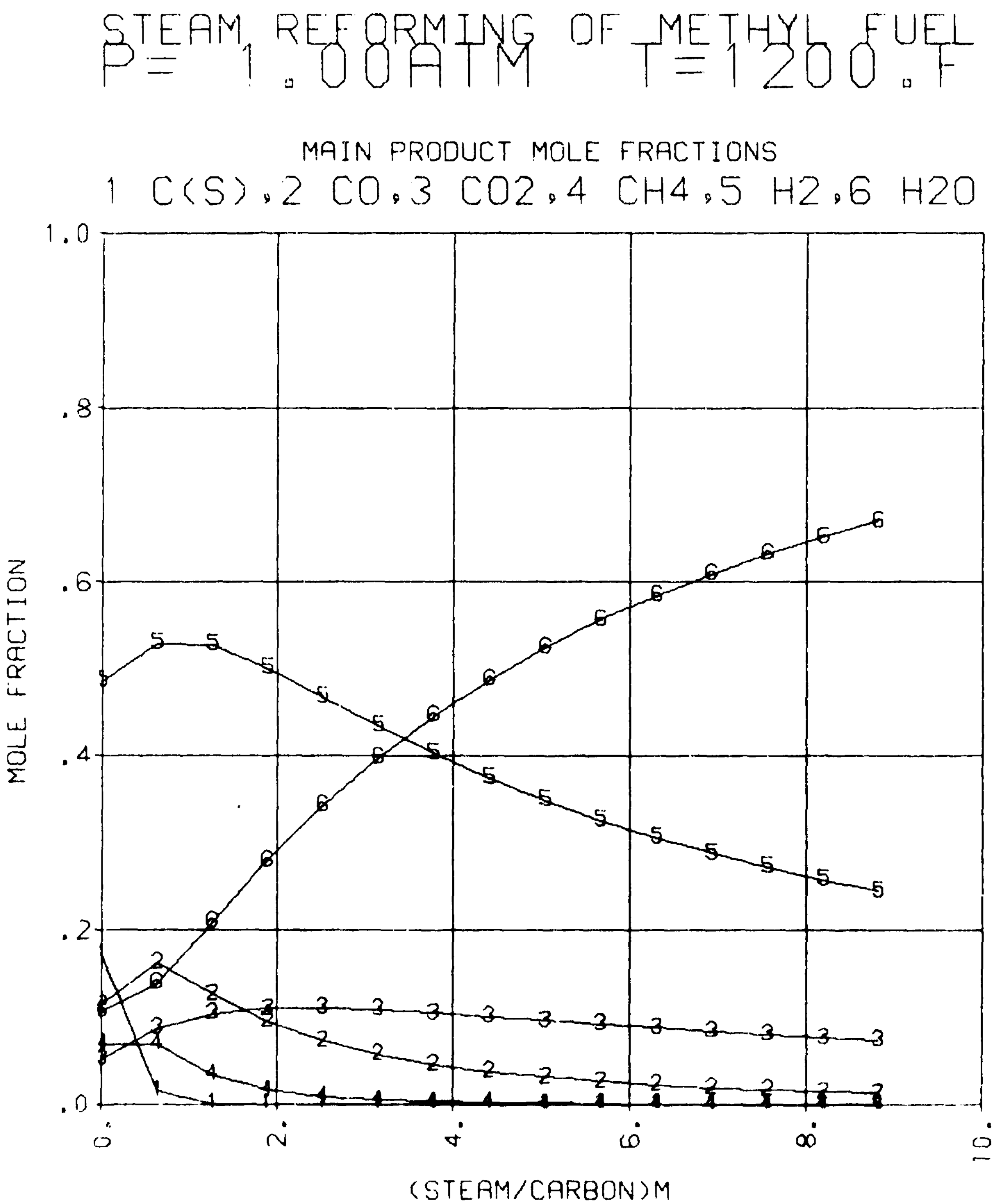
STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 800.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 4.



STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1000.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
(STEAM/CARBON)M

FIGURE 5.



STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1200.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 6.

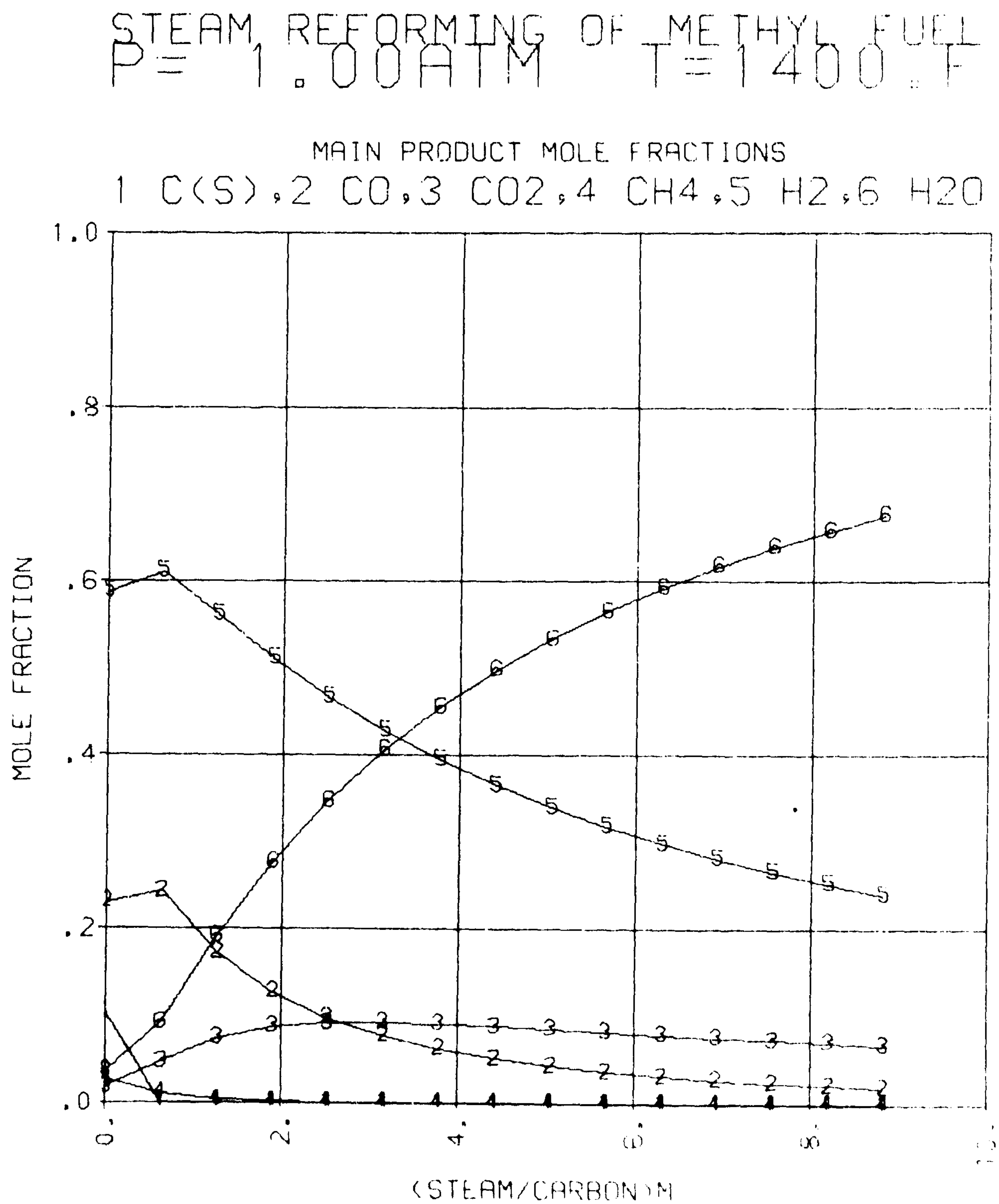
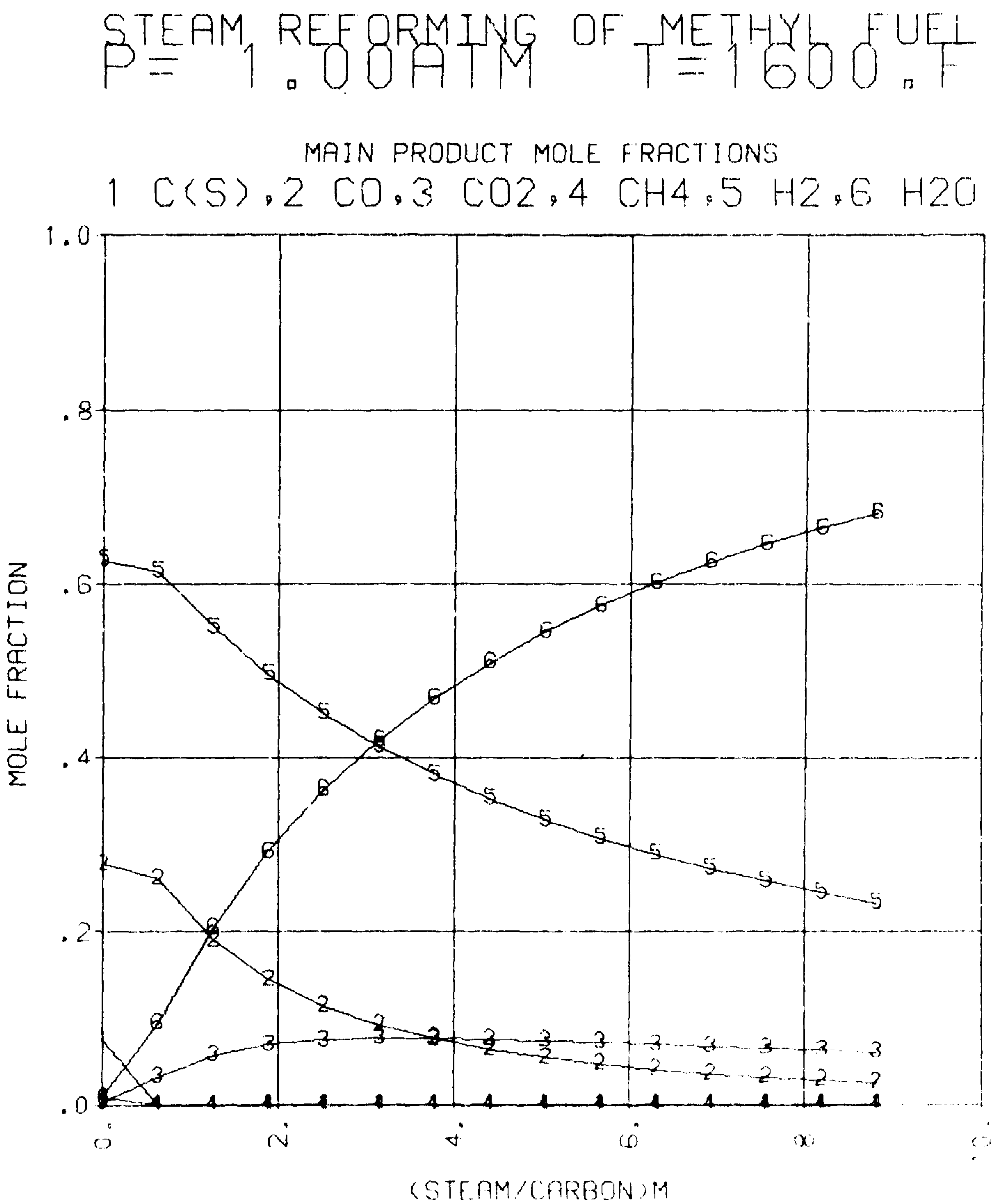
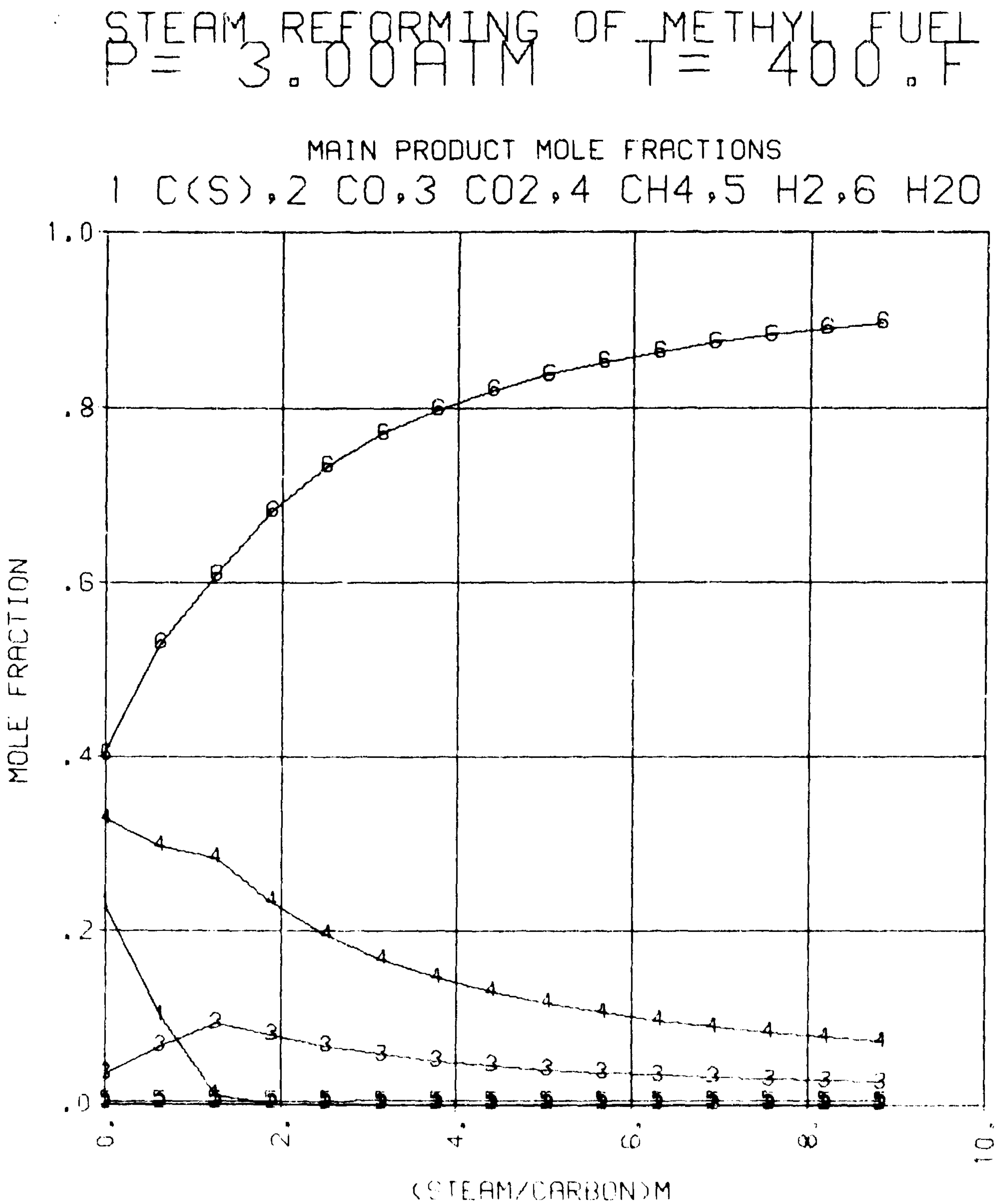

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
(STEAM/CARBON)M

FIGURE 7.



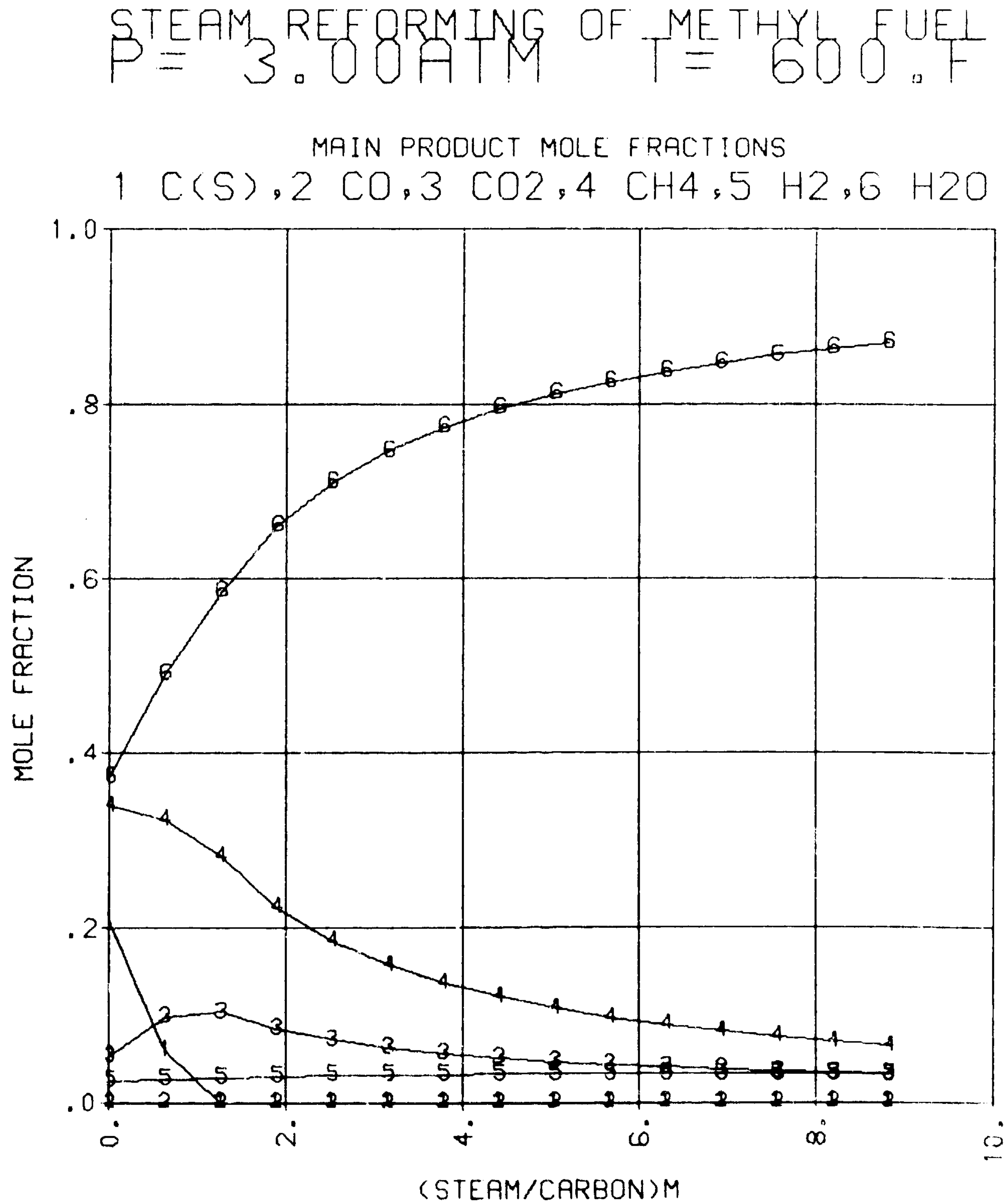
STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
(STEAM/CARBON)M

FIGURE 8.



STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 9.



STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 10.

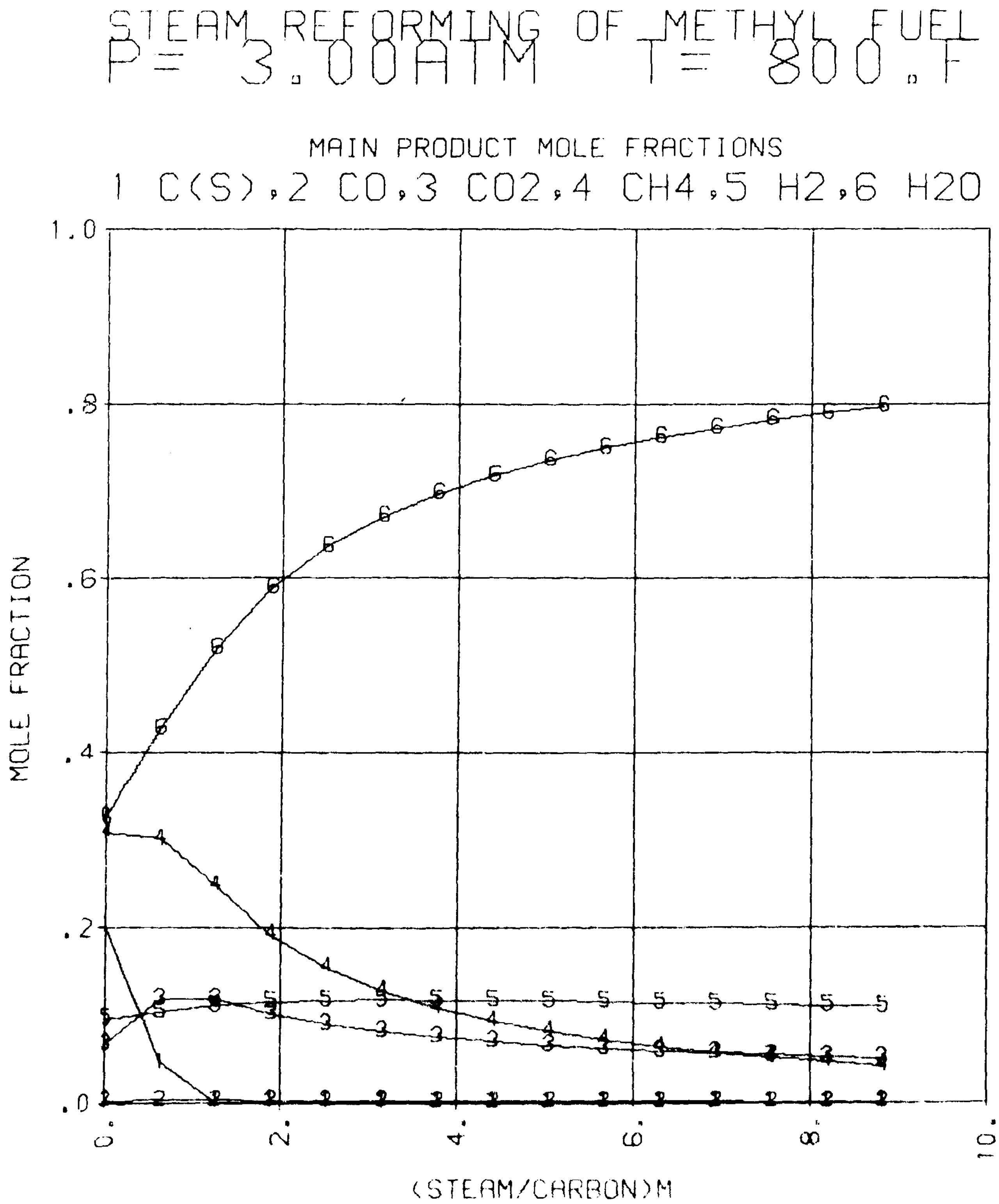

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 800.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 11.

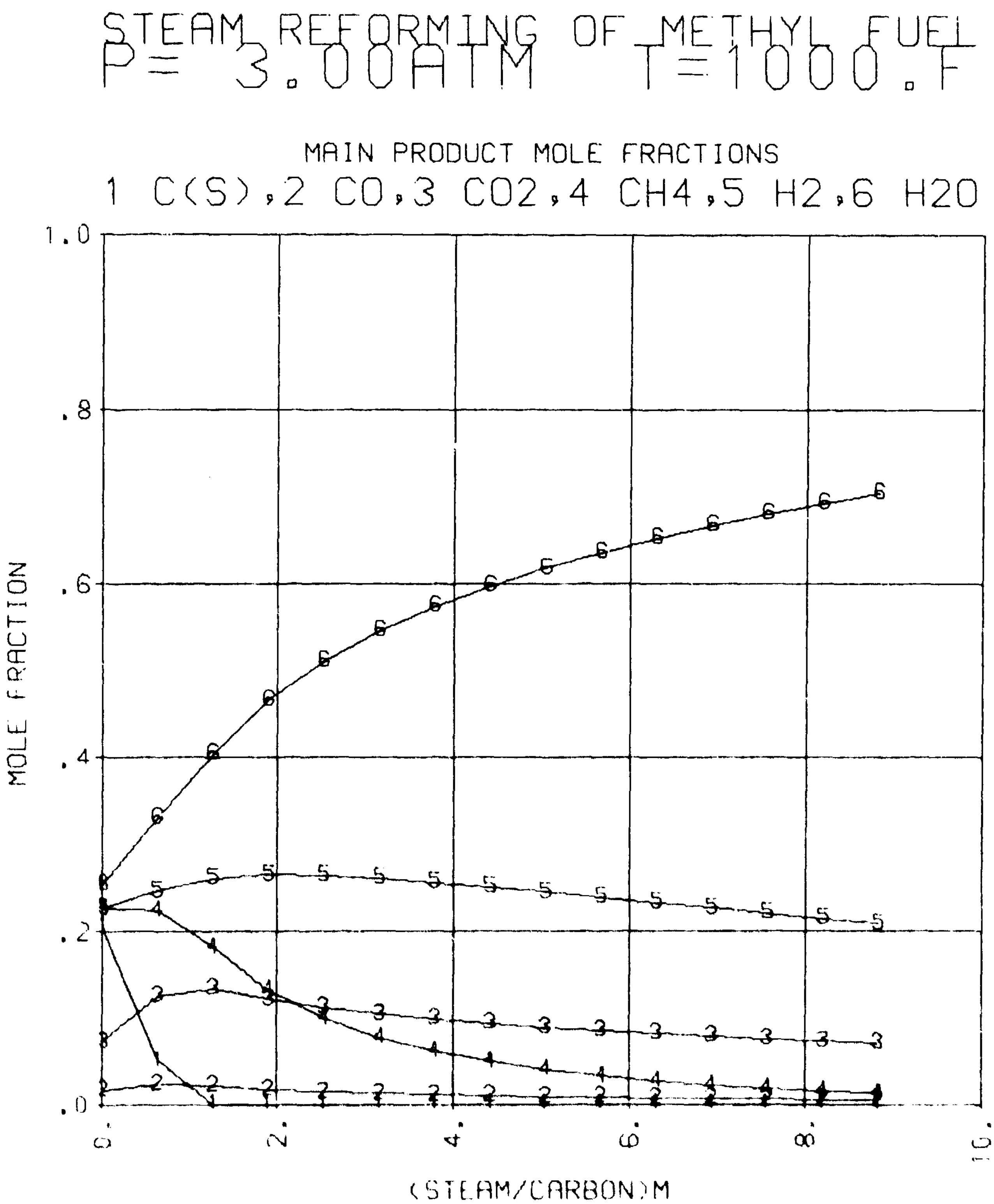
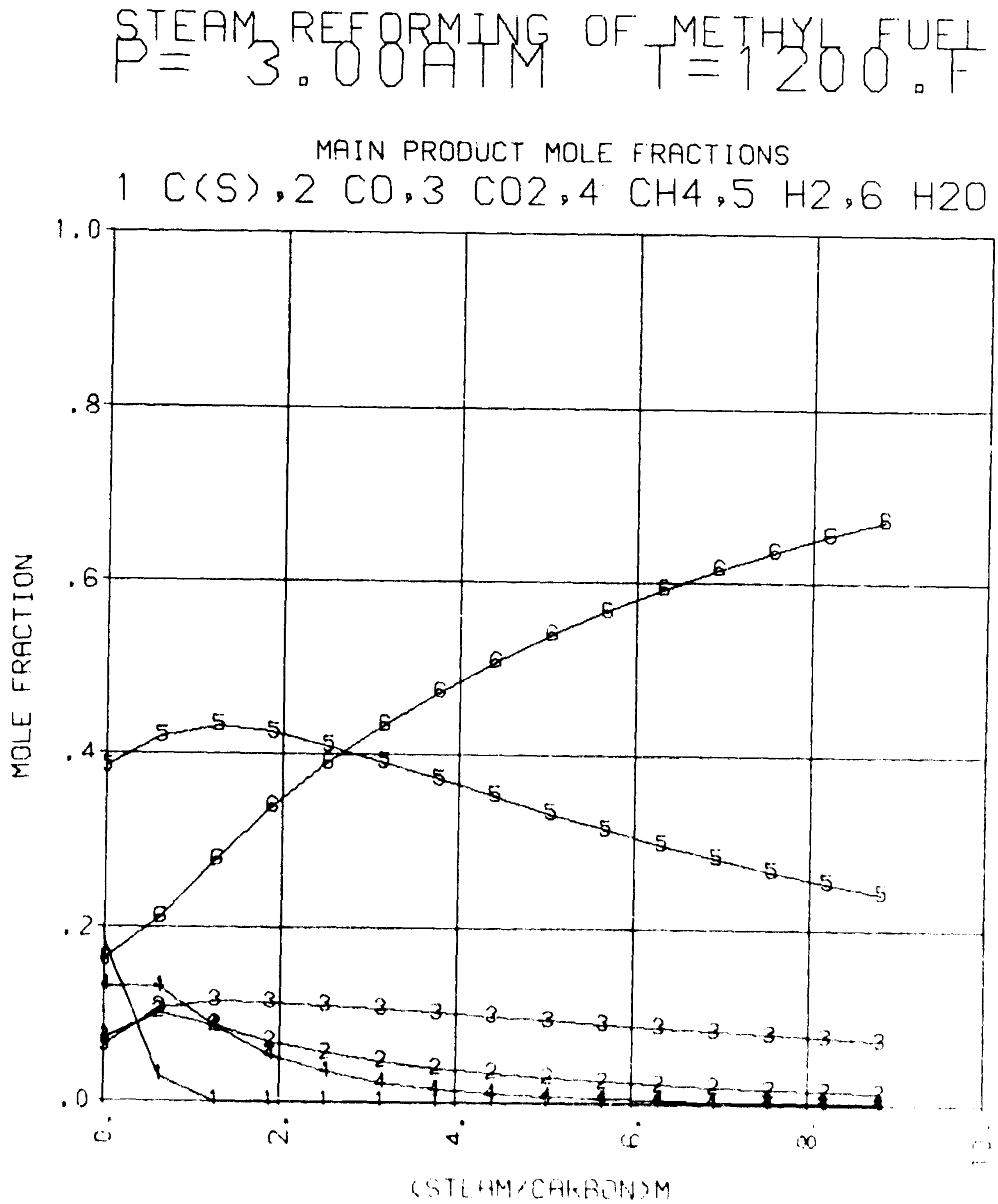

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1000.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 12.


STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1200.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
(STEAM/CARBON)M

FIGURE

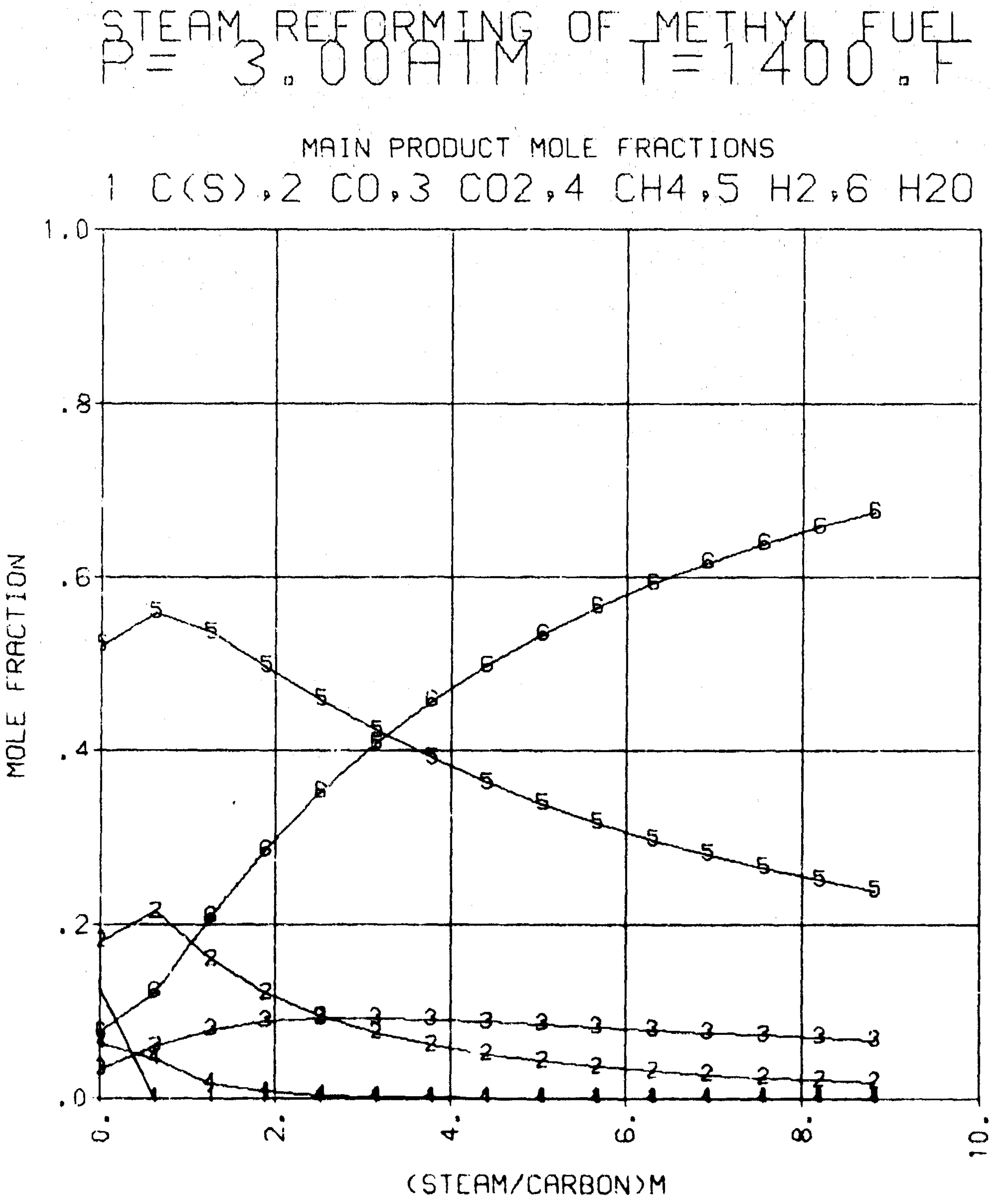

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 14.

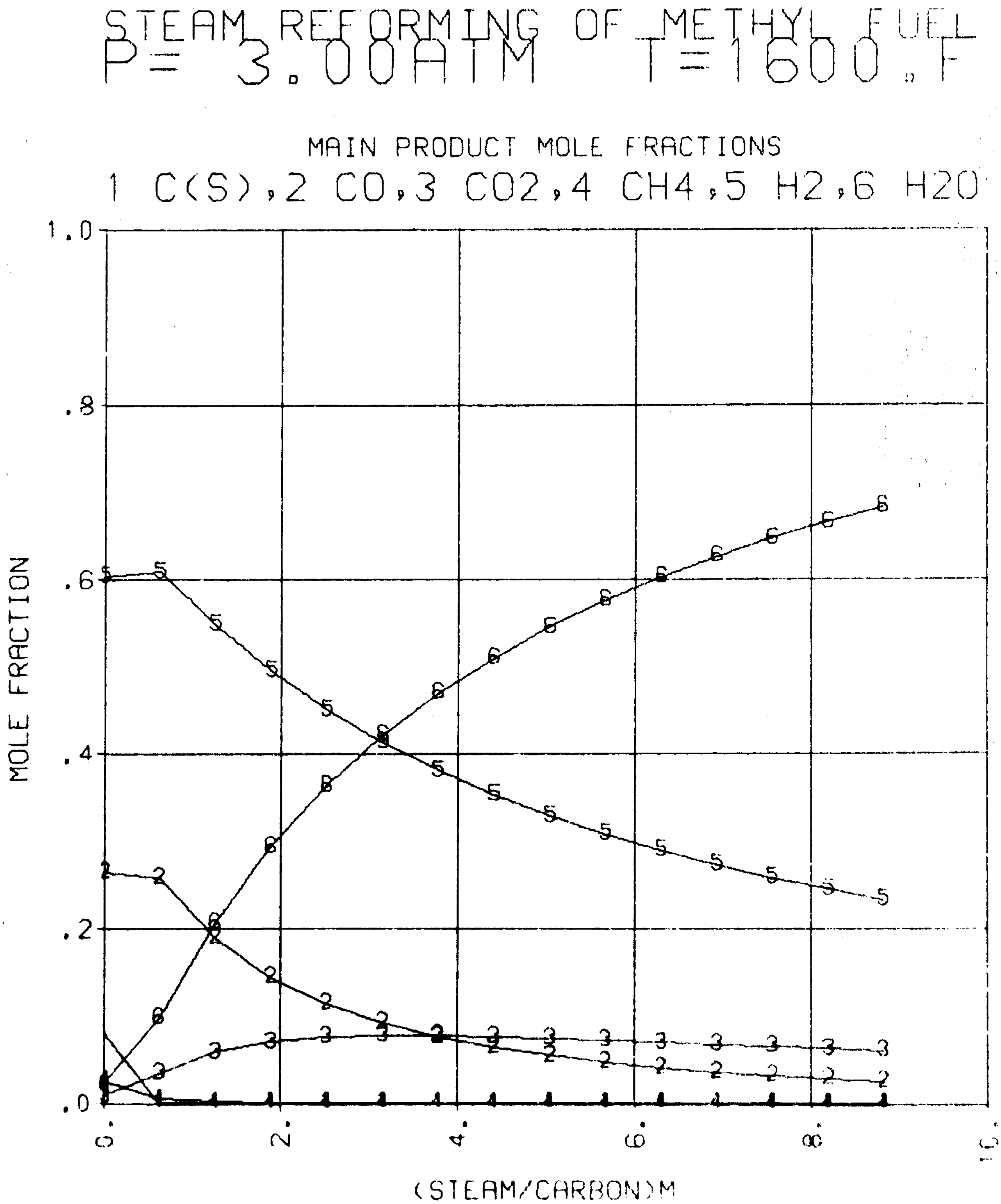
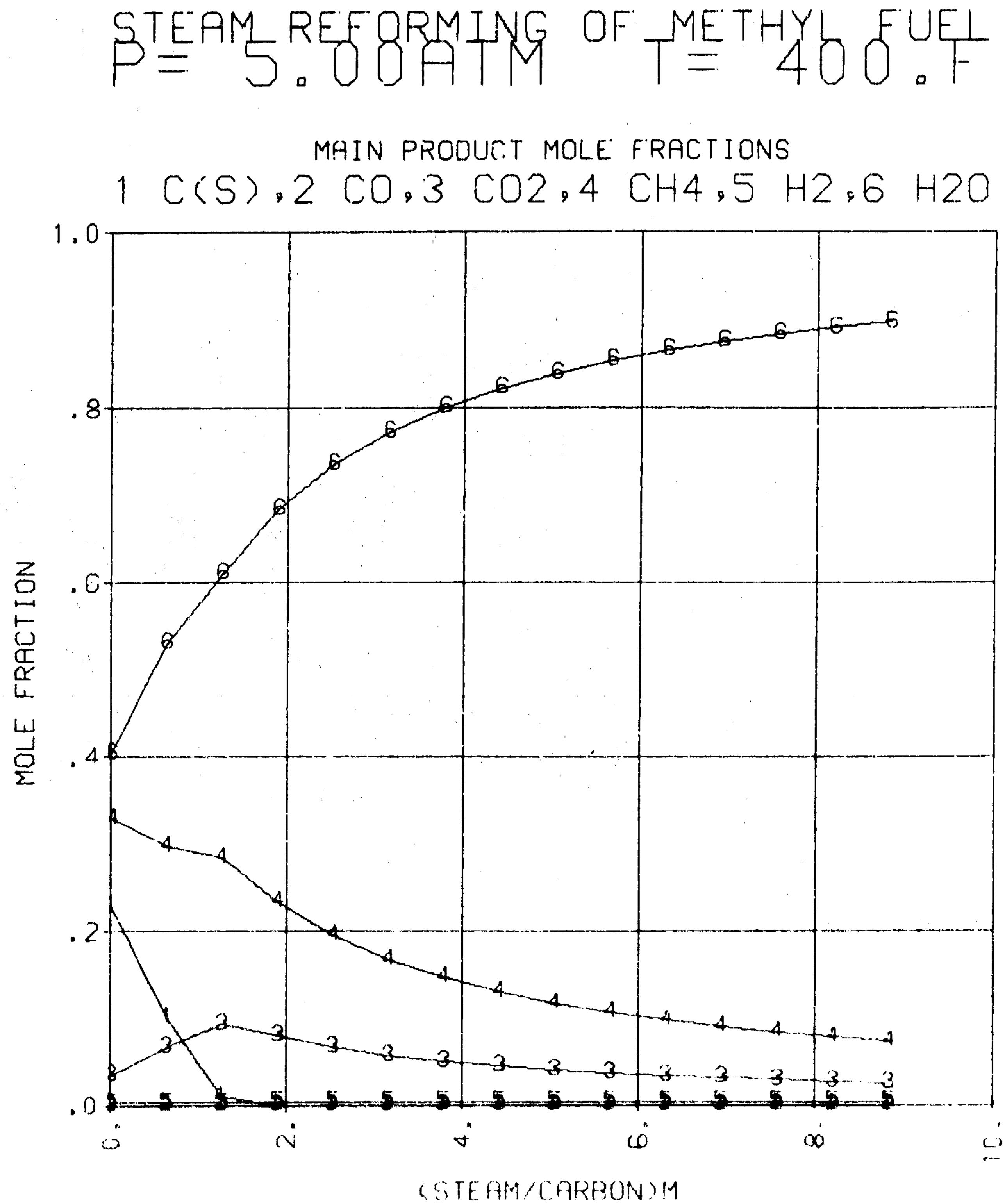

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 15.



STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T= 400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 16.

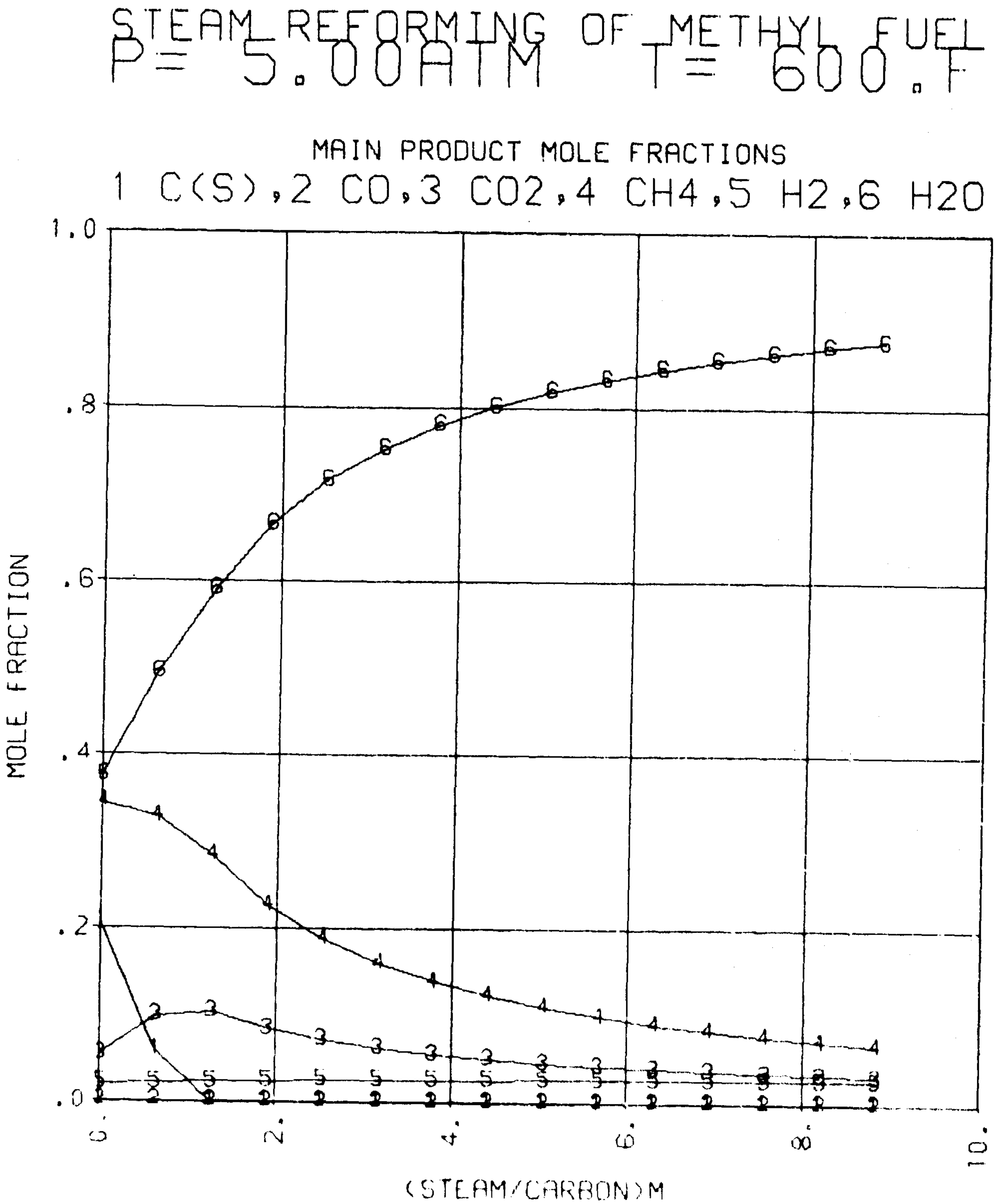

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T= 600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 17.

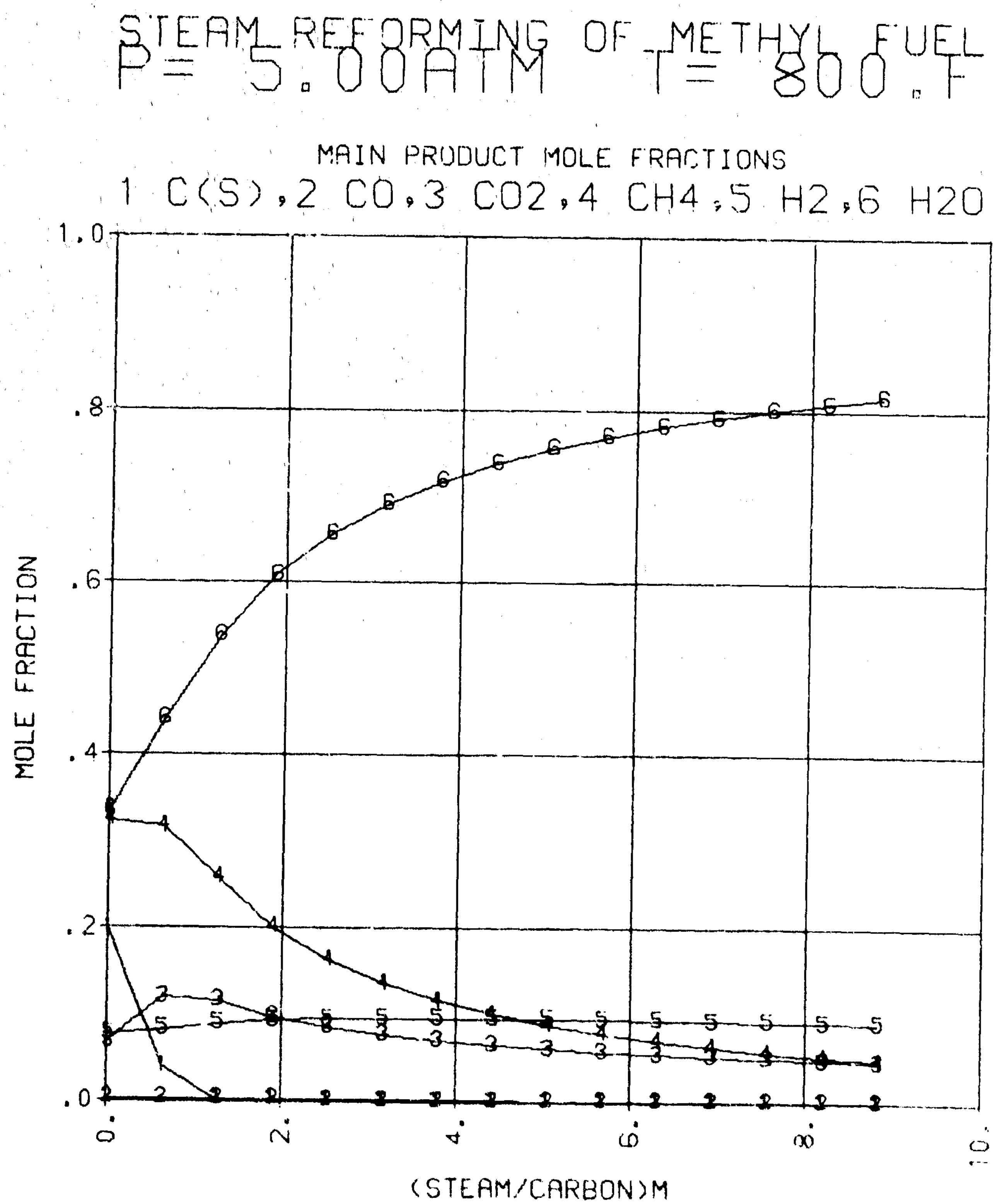

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T= 800.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 18.

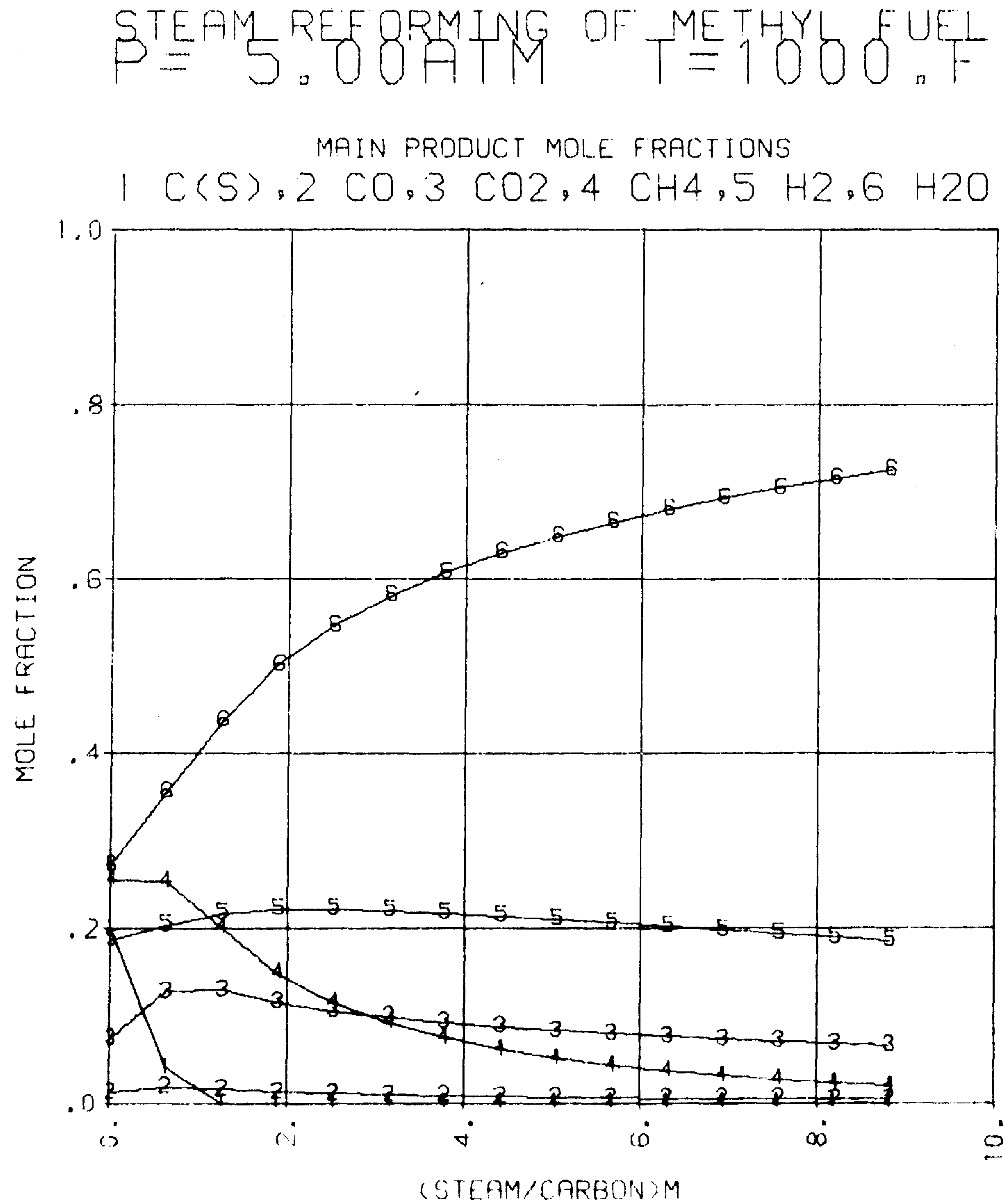

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1000.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 19.

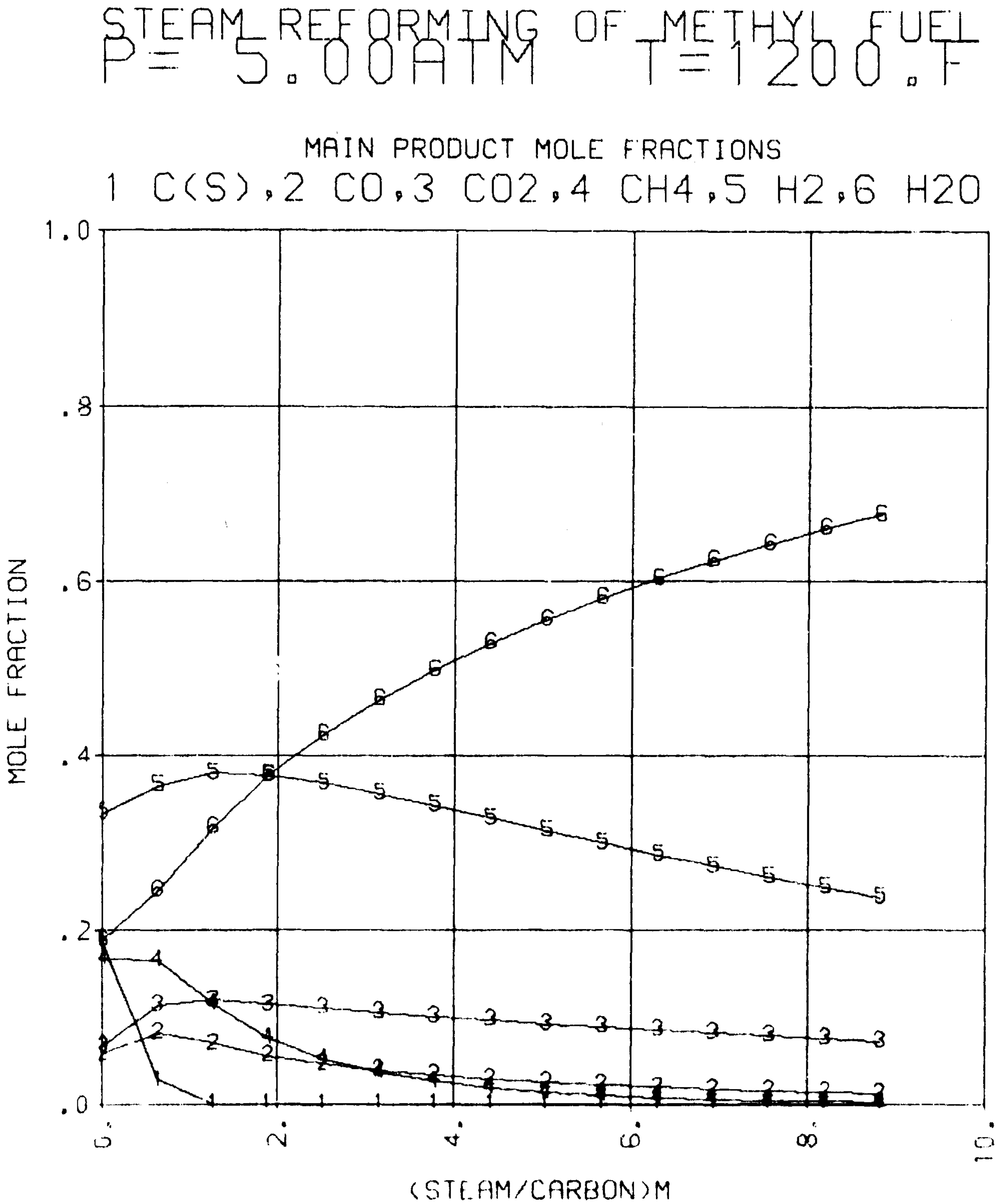

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1200.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
1.0
.8
.6
.4
.2
.0
MOLE FRACTION
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 20.

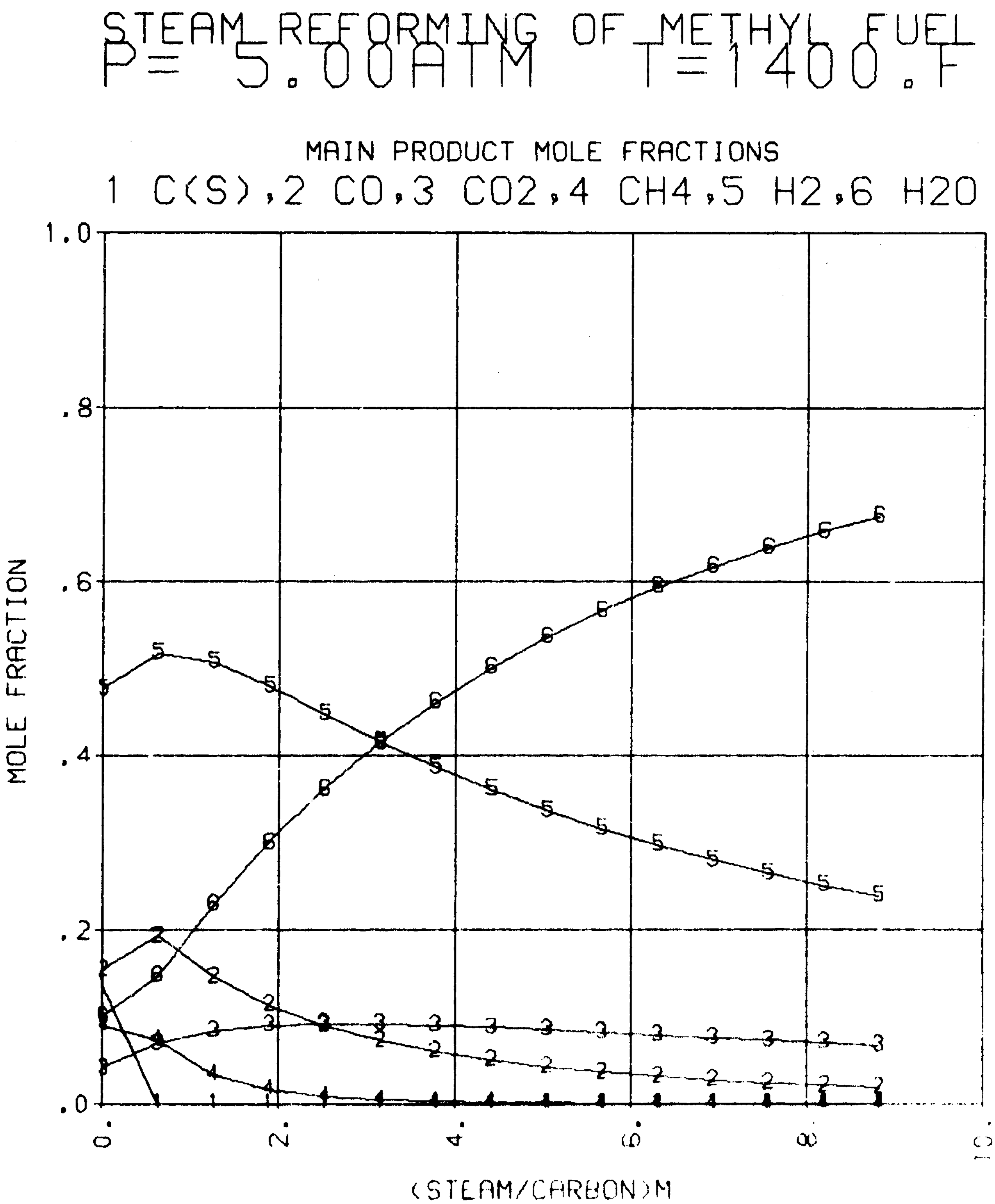

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1400.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
(STEAM/CARBON)M

FIGURE 21.

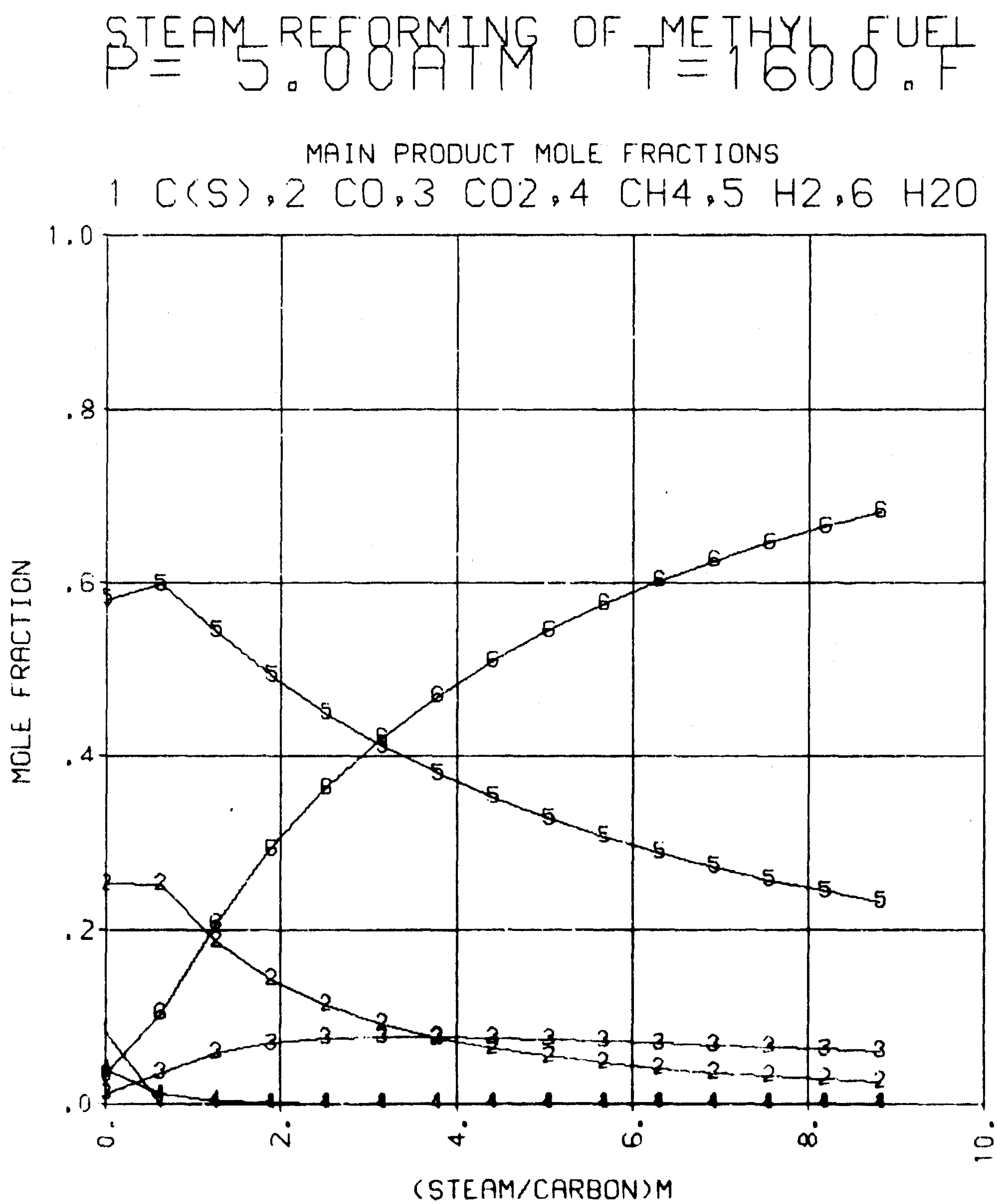
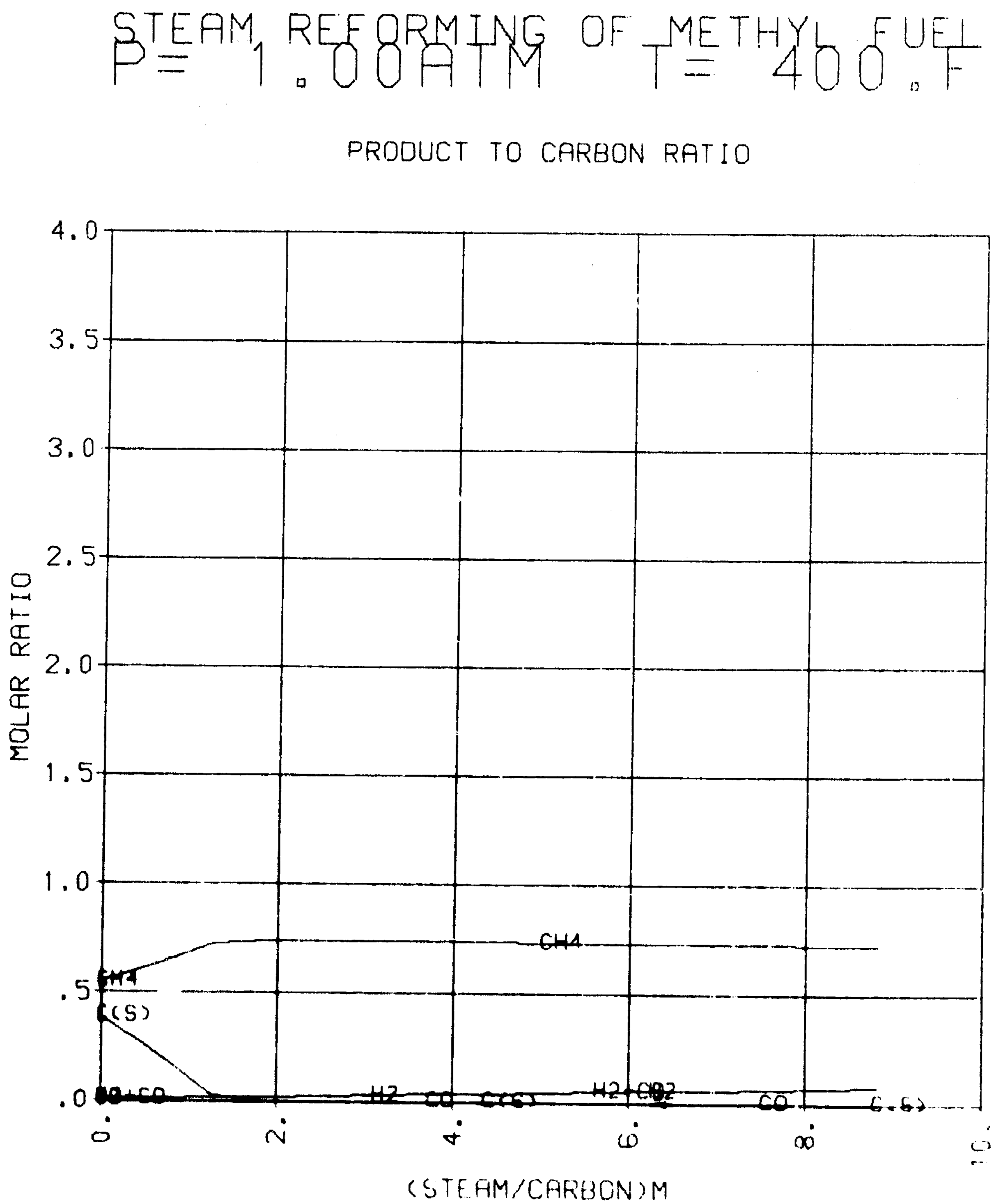

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1600.F
MAIN PRODUCT MOLE FRACTIONS
1 C(S),2 CO,3 CO2,4 CH4,5 H2,6 H2O
MOLE FRACTION
1.0
.8
.6
.4
.2
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 22.



STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 400.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
(STEAM/CARBON)M
CH4
C(S)
H2
CO

FIGURE 23.

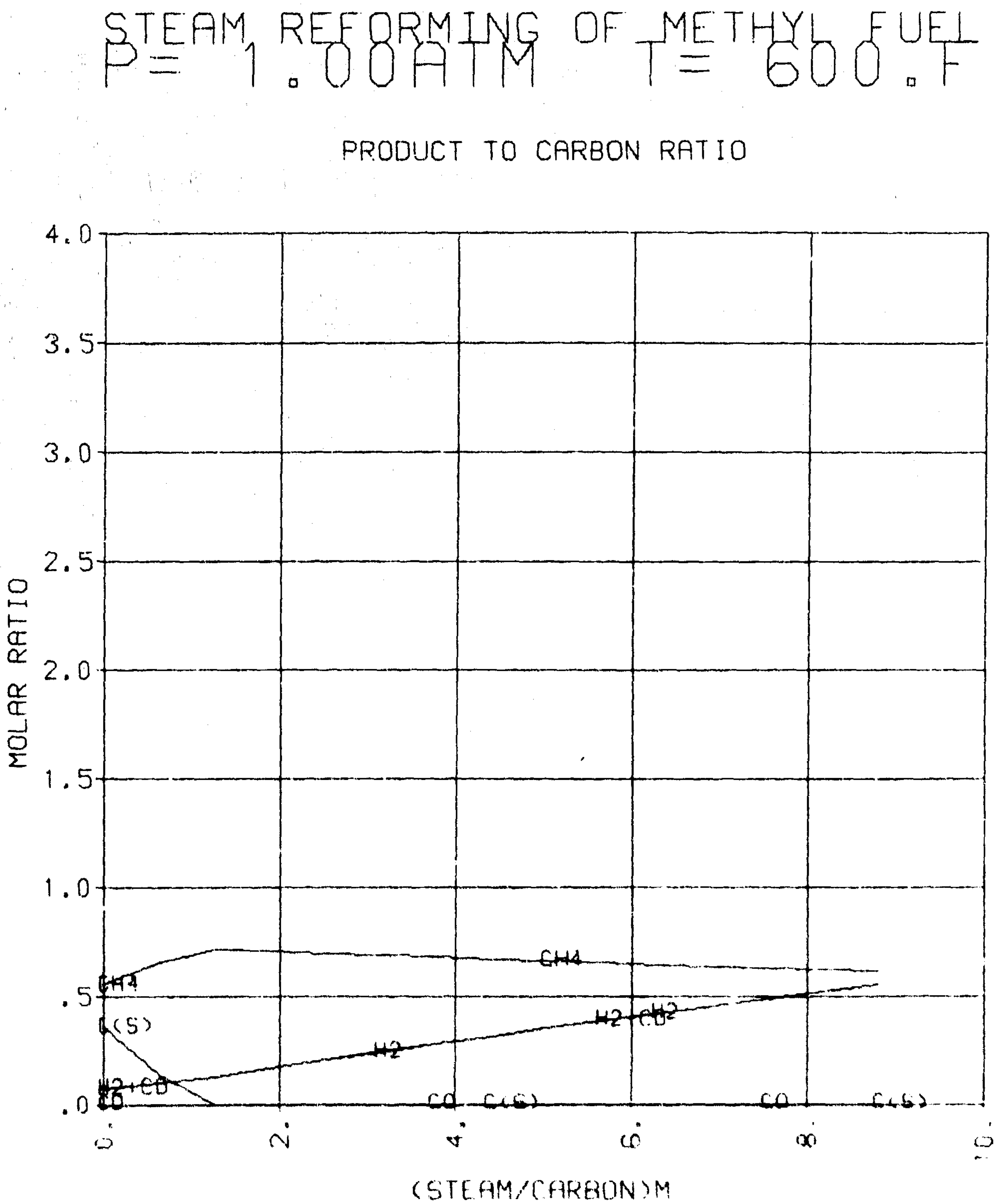

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 600.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M
CH4
CH4
C(S)
H2+CO
CO
H2
H2+CO2
H2
CO
C(S)
CO
C(S)

FIGURE 24.

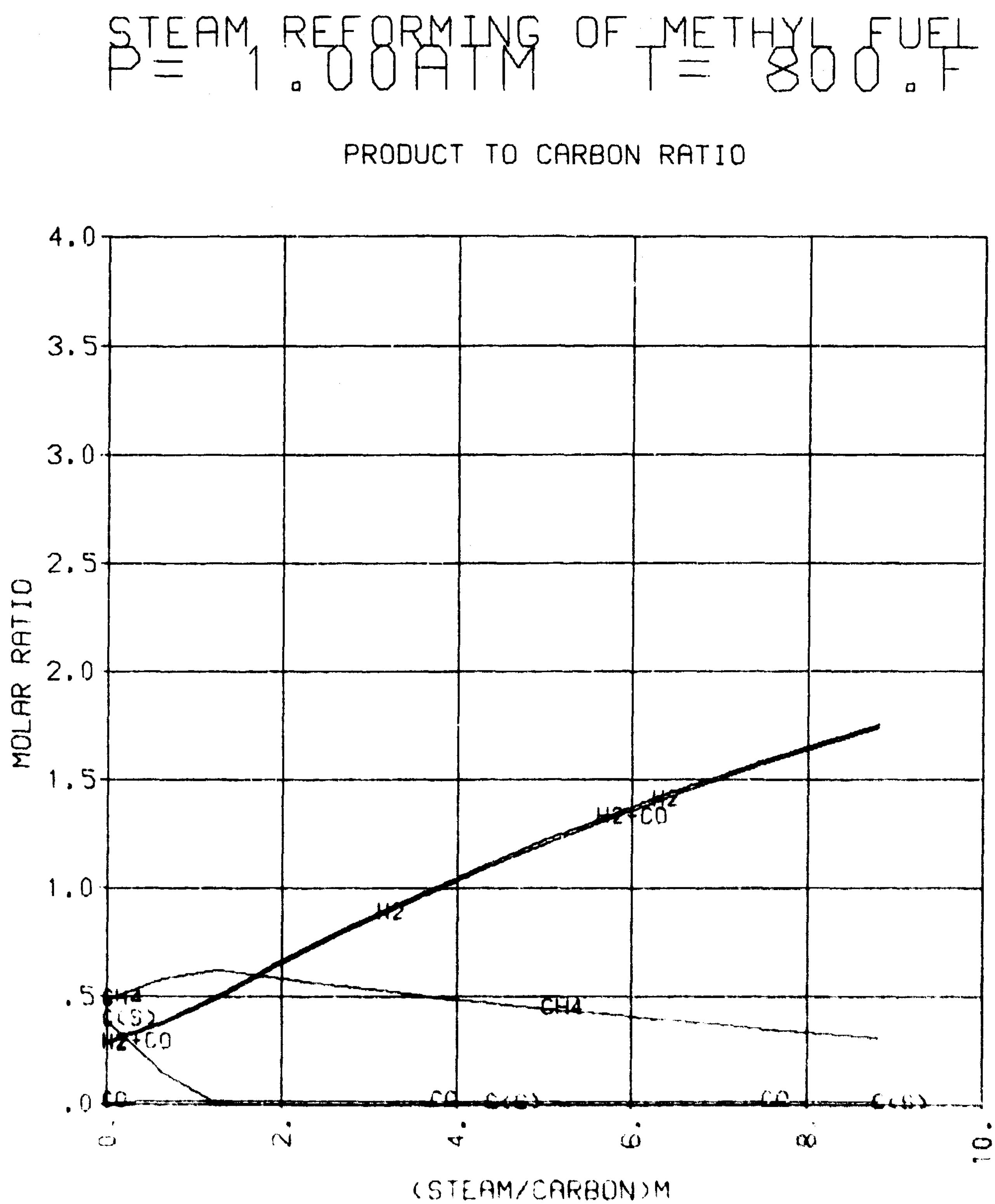

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T= 800.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M
H2
H2+CO
CH4
C(S)
CO

FIGURE 25.

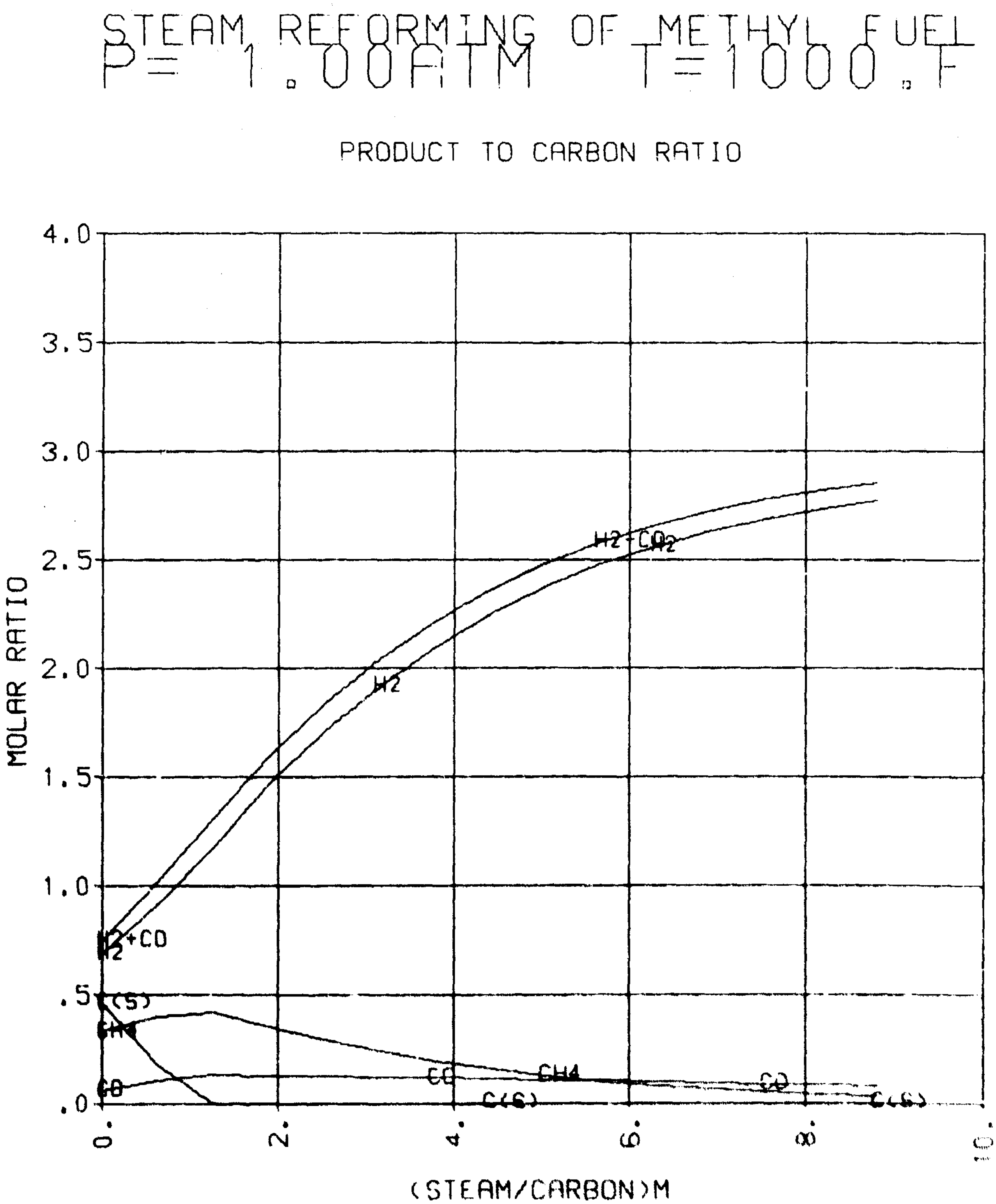

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1000.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO2
H2
H2+CO
C(S)
CH4
CO
C(G)
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 26.

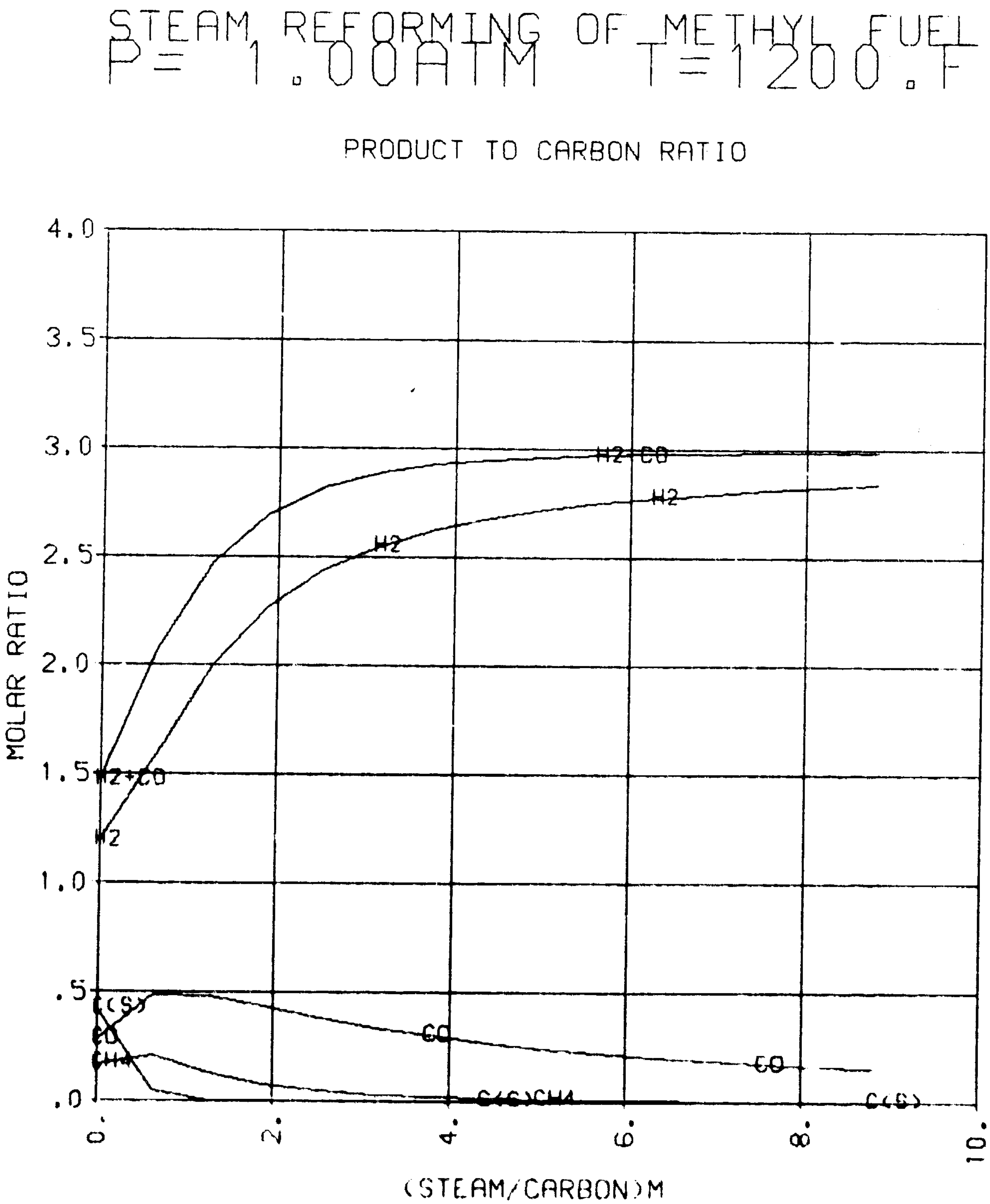

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1200.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
H2
H2+CO
H2
C(S)
CO
CH4
CO
C(S)CH4
CO
C(S)
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 27.

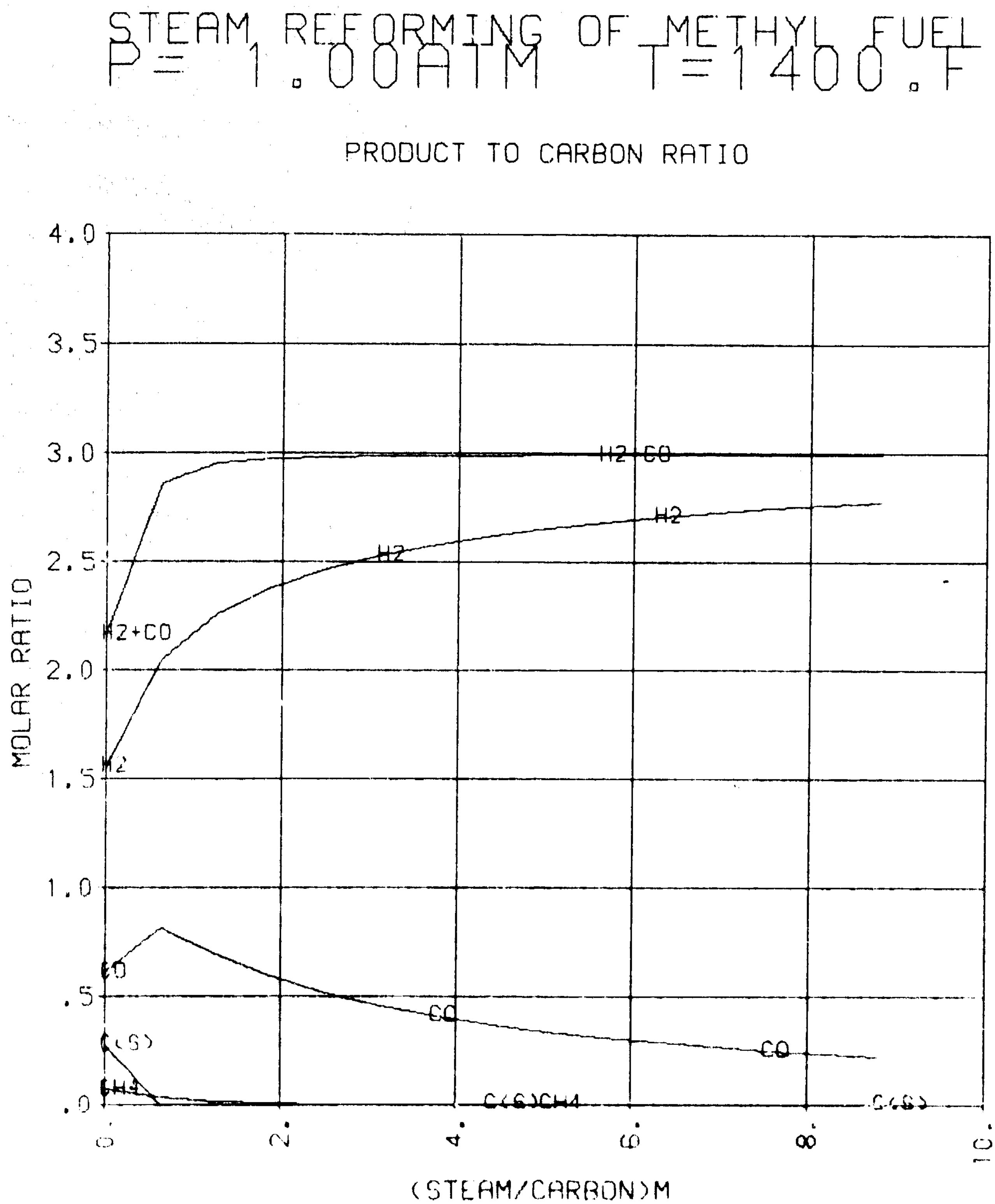
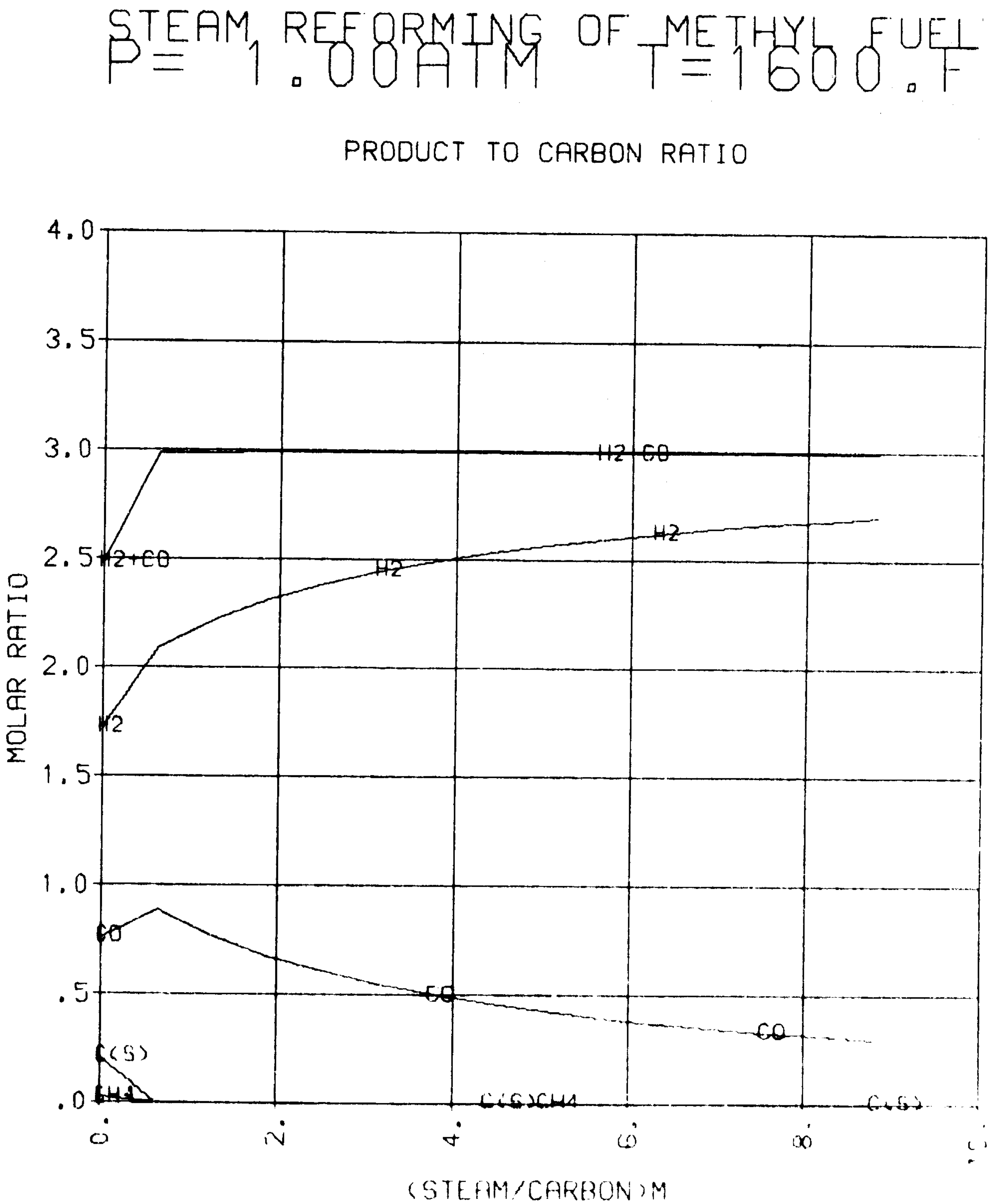

STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1400.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M
H2+CO
H2
CO
C(S)
CH4
C(S)CH4

FIGURE 28.



STEAM REFORMING OF METHYL FUEL
P= 1.00ATM T=1600.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
CO
C(S)
CH4
C(S)CH4
0.
2.
4.
6.
8.
(STEAM/CARBON)M

FIGURE 29.

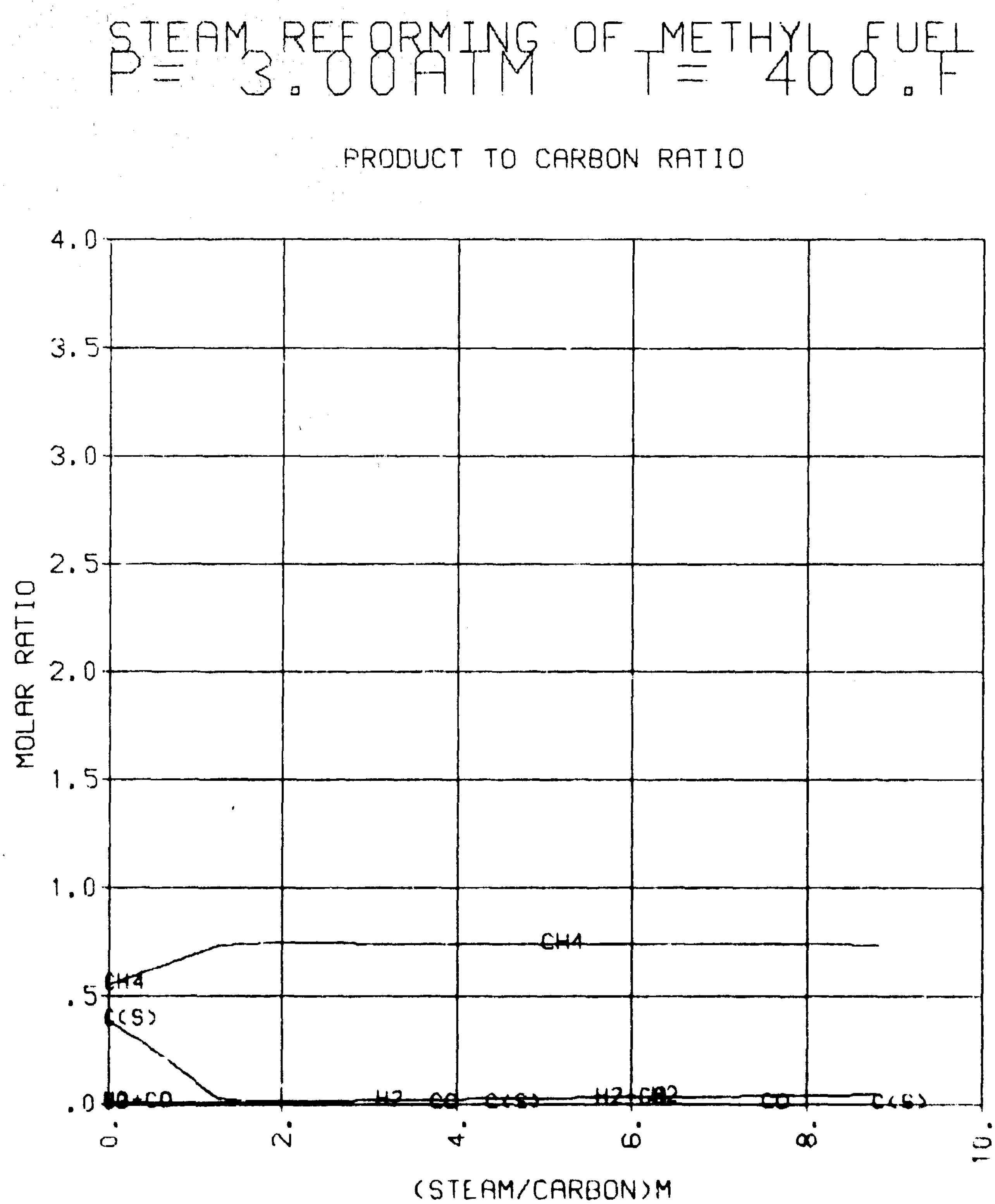

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 400.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
CH4
CH4
C(S)
H2
CO
C(S)
H2+CO2
CO
C(S)
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 30.

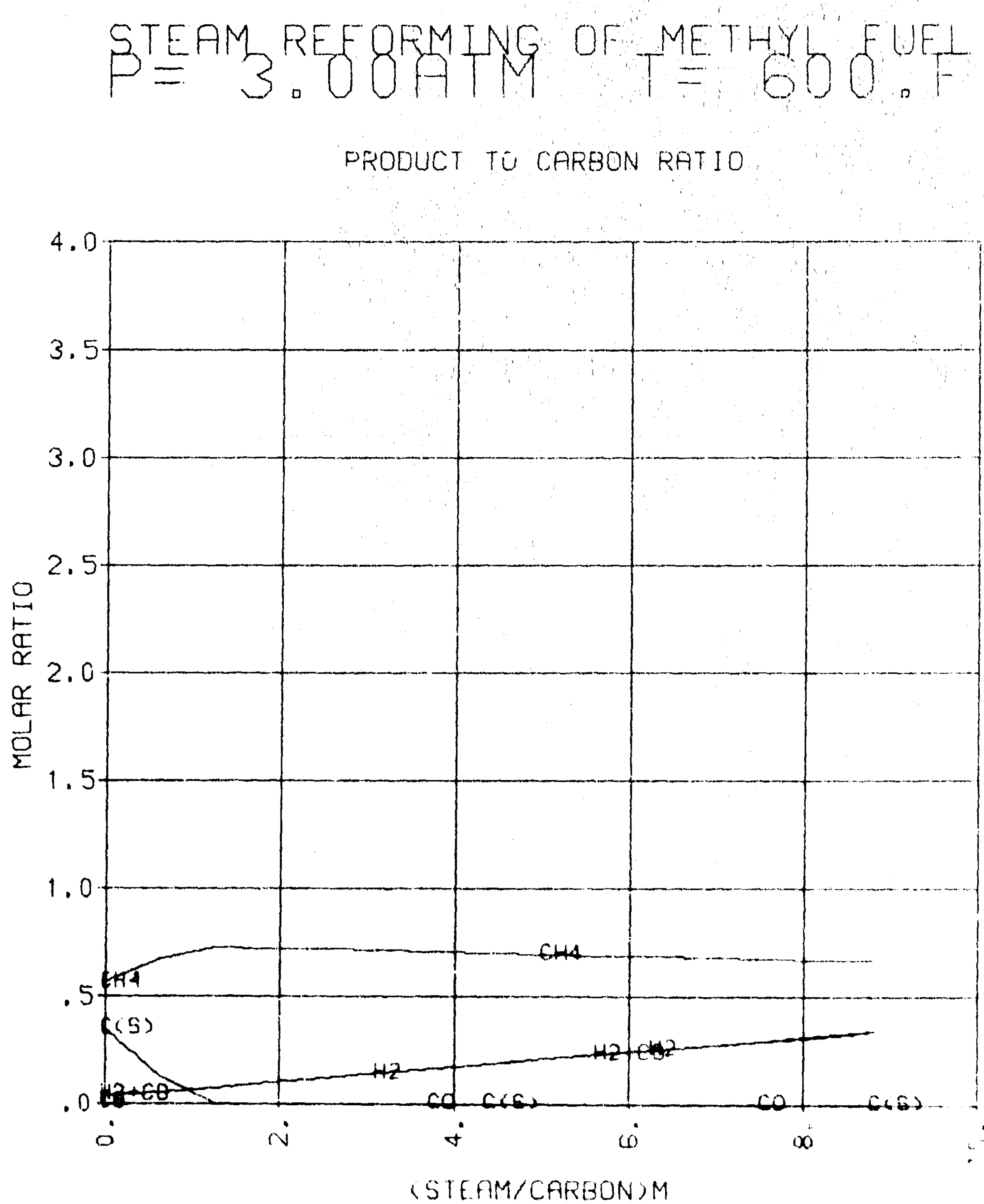

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 600.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
CH4
CH4
C(S)
H2+CO
H2
H2+CO2
CO
C(S)
CO
C(S)
0.
2.
4.
6.
8.
(STEAM/CARBON)M

FIGURE 31.

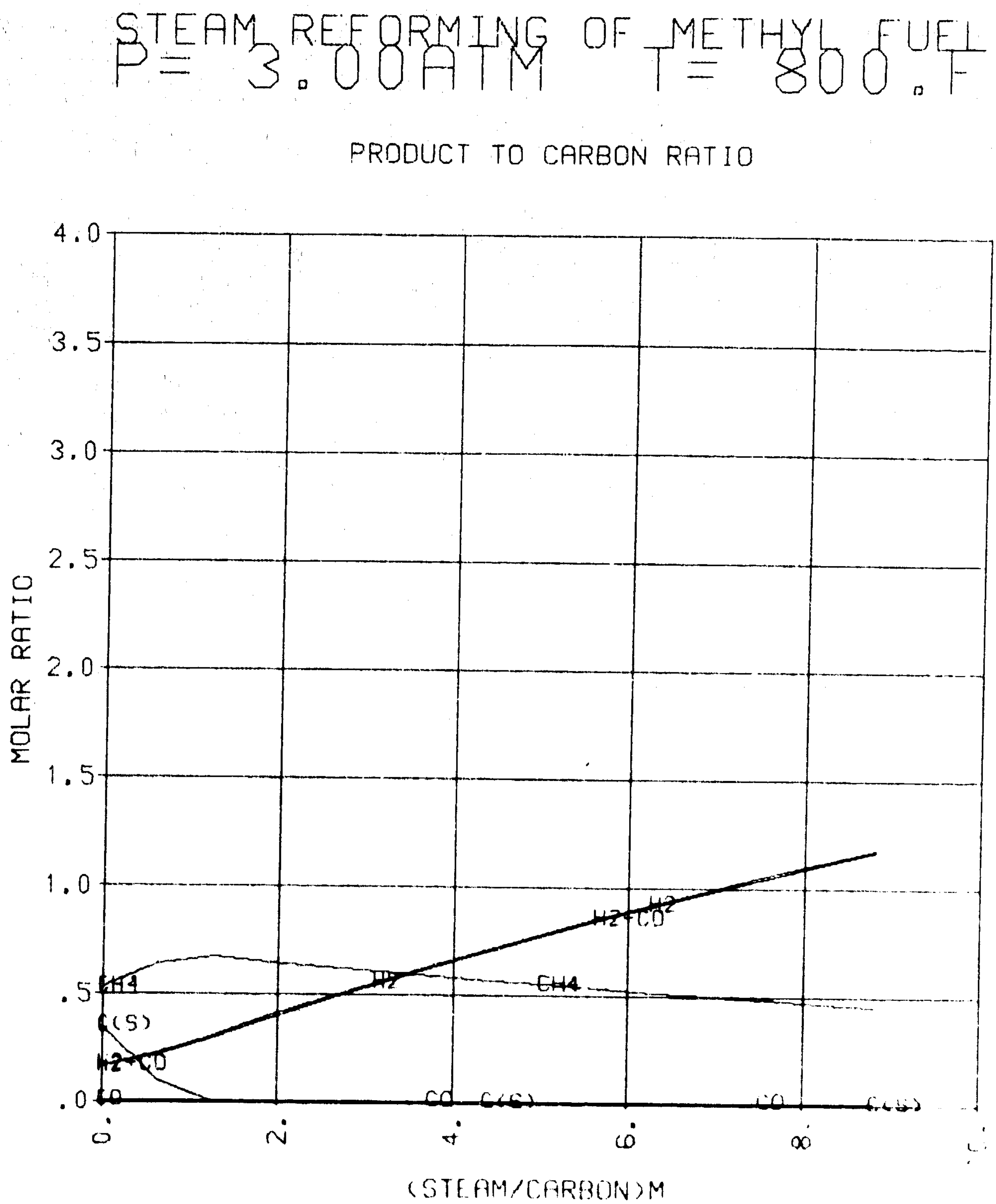
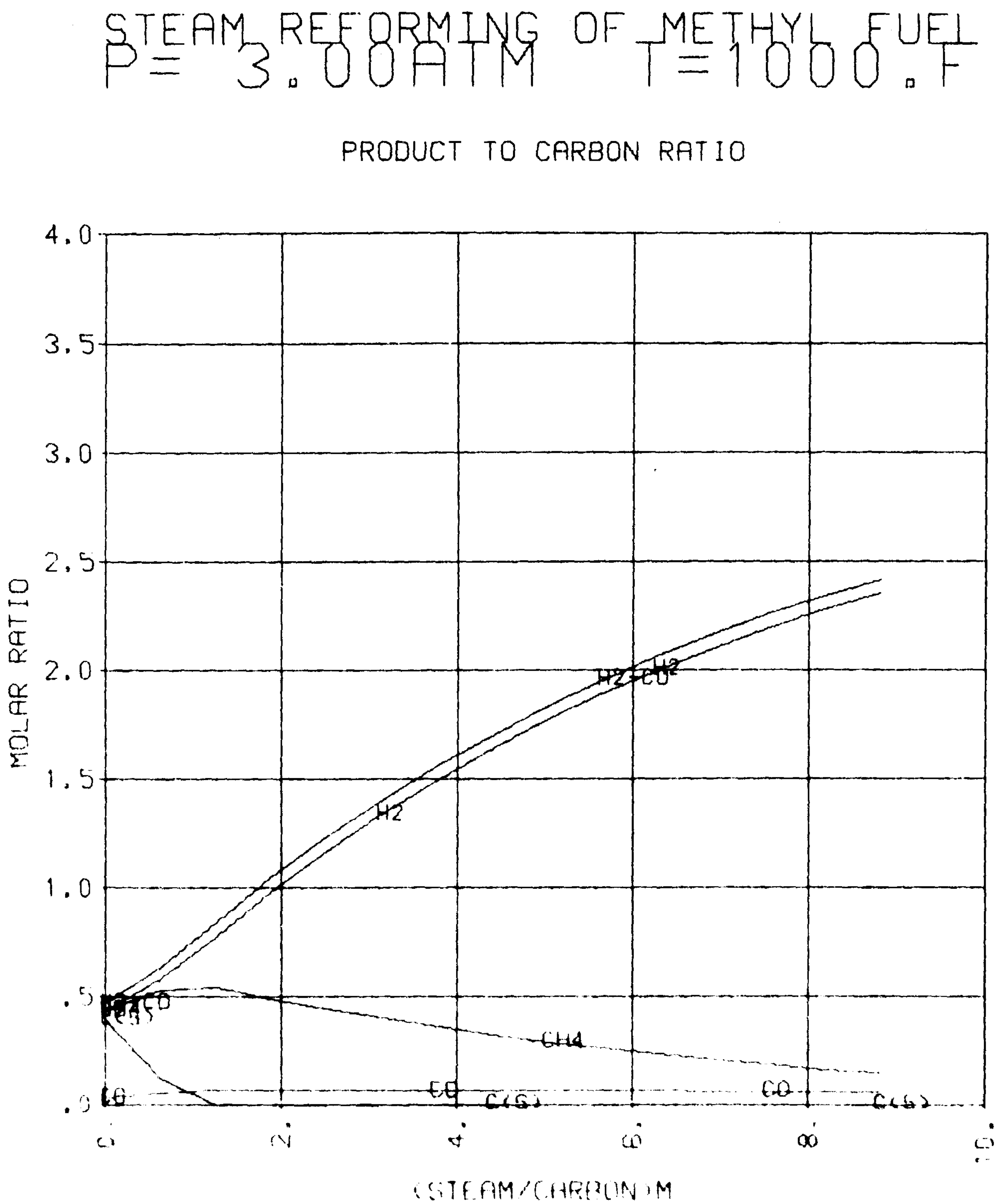
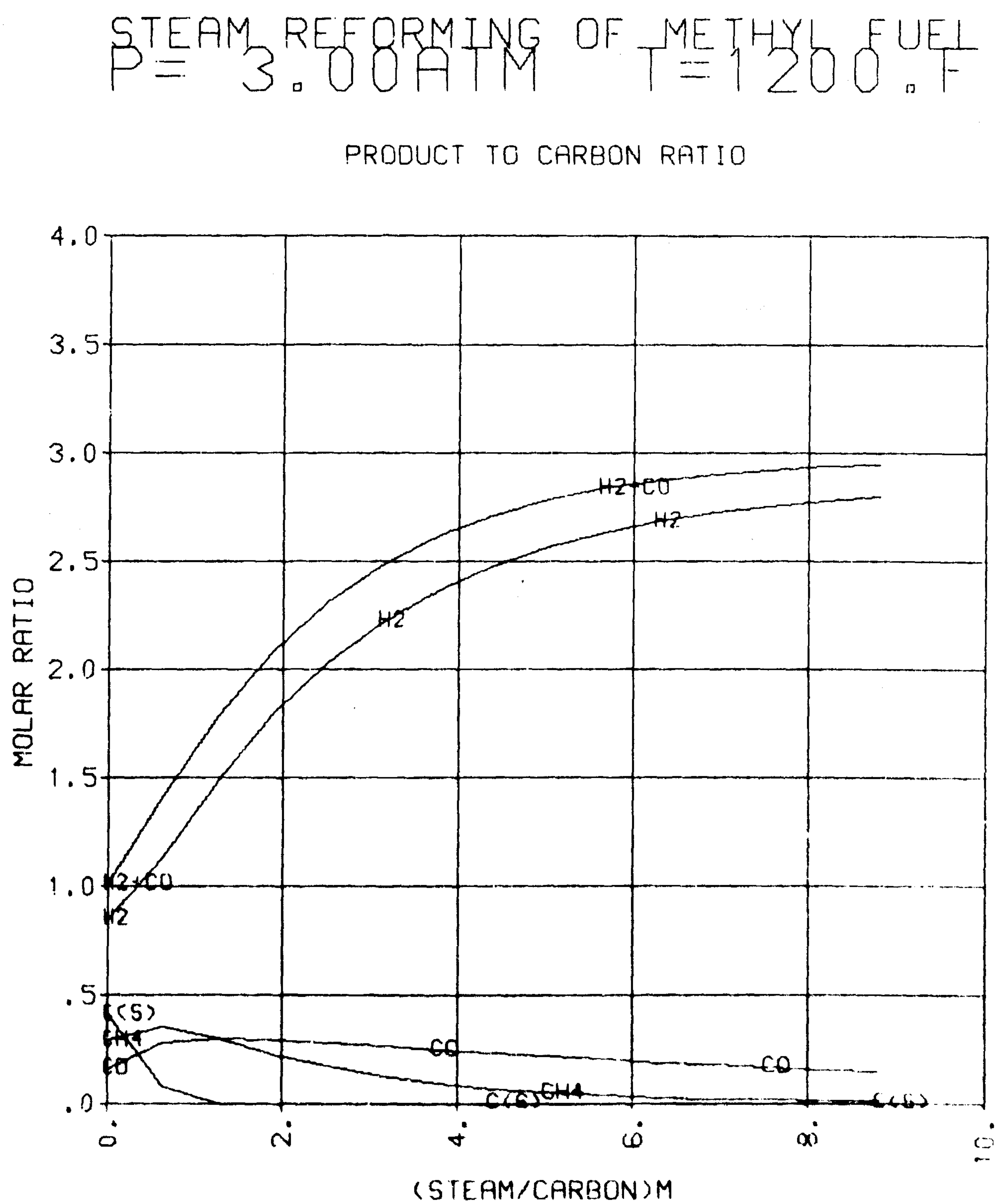

STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T= 800.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
(STEAM/CARBON)M
CH4
C(S)
H2+CO
CO
H2
CO
C(S)
CH4
H2+CO
H2

FIGURE 32.



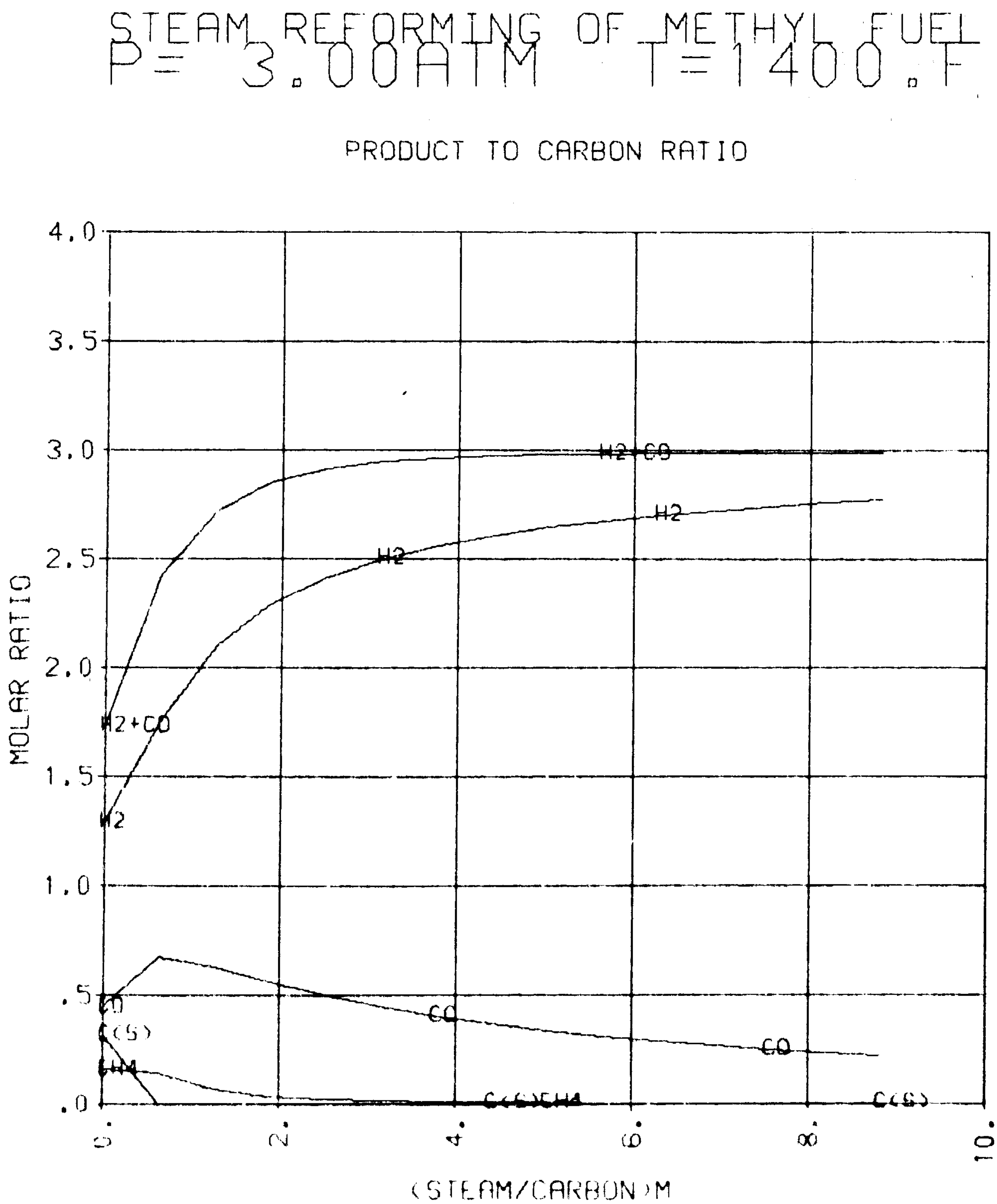
STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1000.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2
H2+CO
CH4
CO
C(S)
(STEAM/CARBON)M

FIGURE 33.



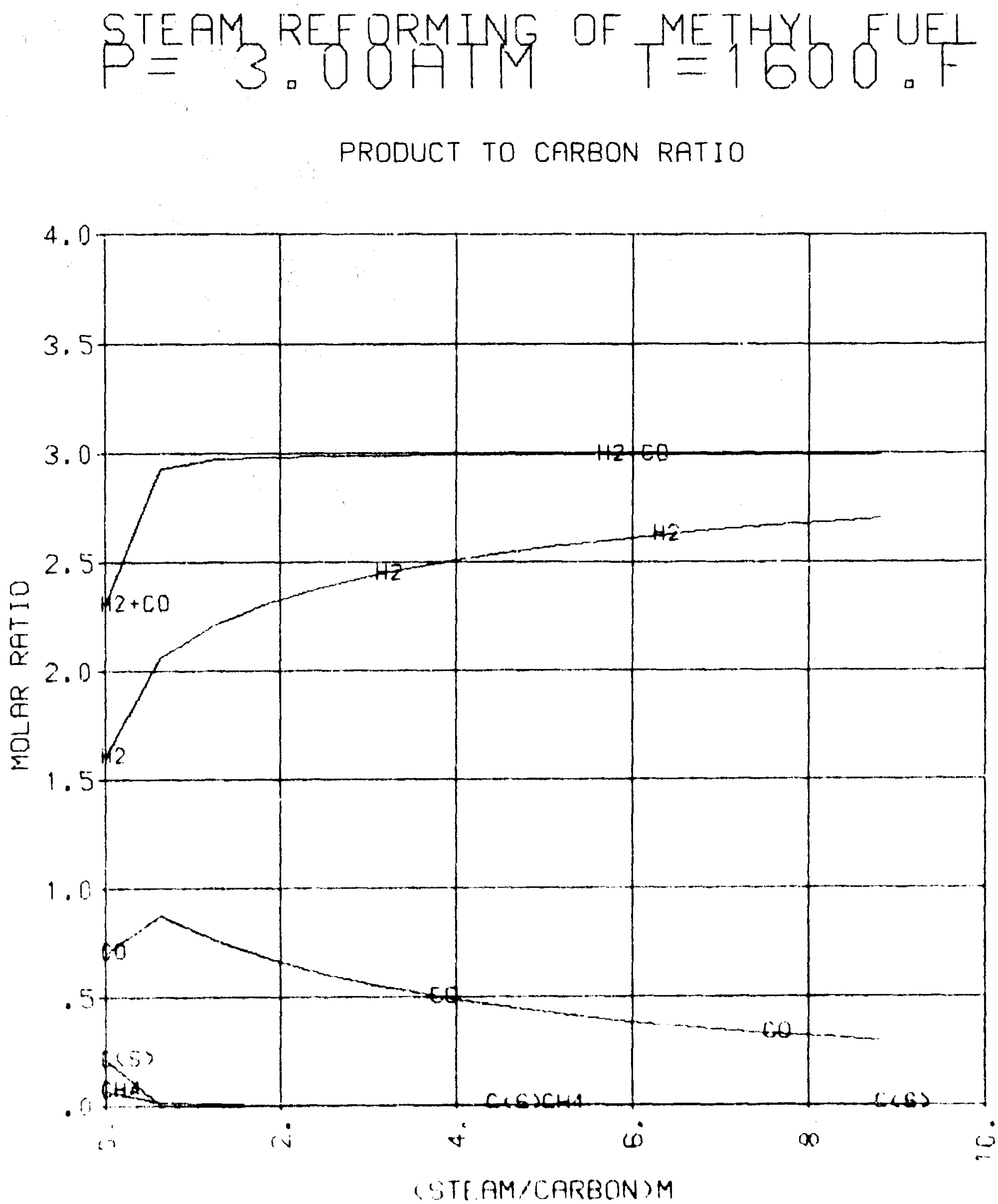
STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1200.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
(STEAM/CARBON)M
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
10.
H2+CO
H2
C(S)
CH4
CO
C(G)

FIGURE 34.



STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1400.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
CO
C(S)
CH4
C(S)CH4
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 35.



STEAM REFORMING OF METHYL FUEL
P= 3.00ATM T=1600.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
CO
C(S)
CH4
C(S)CH4
(STEAM/CARBON)M

FIGURE 36.

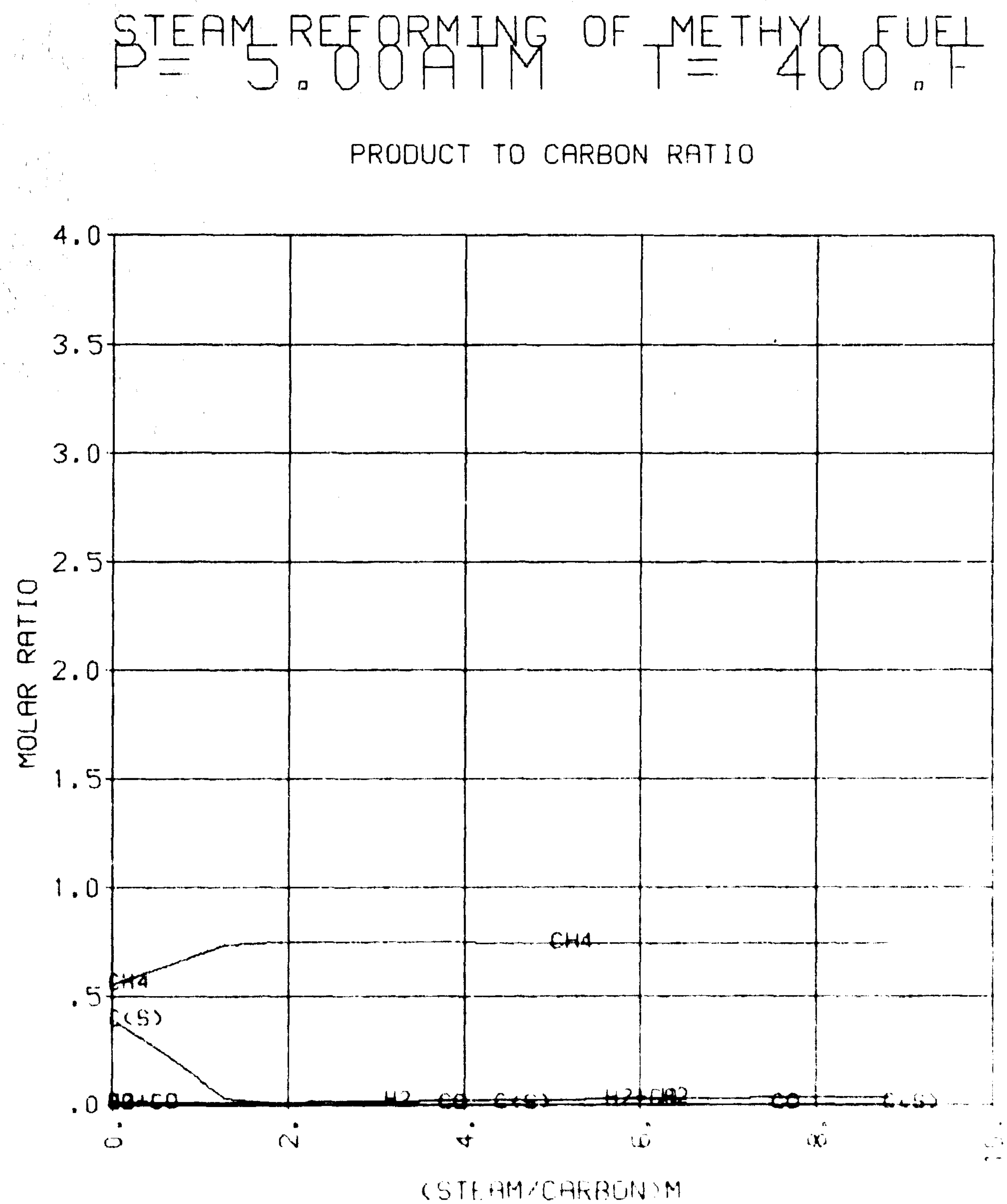

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T= 400.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
CH4
C(S)
H2
CO
(STEAM/CARBON)M

FIGURE 37.

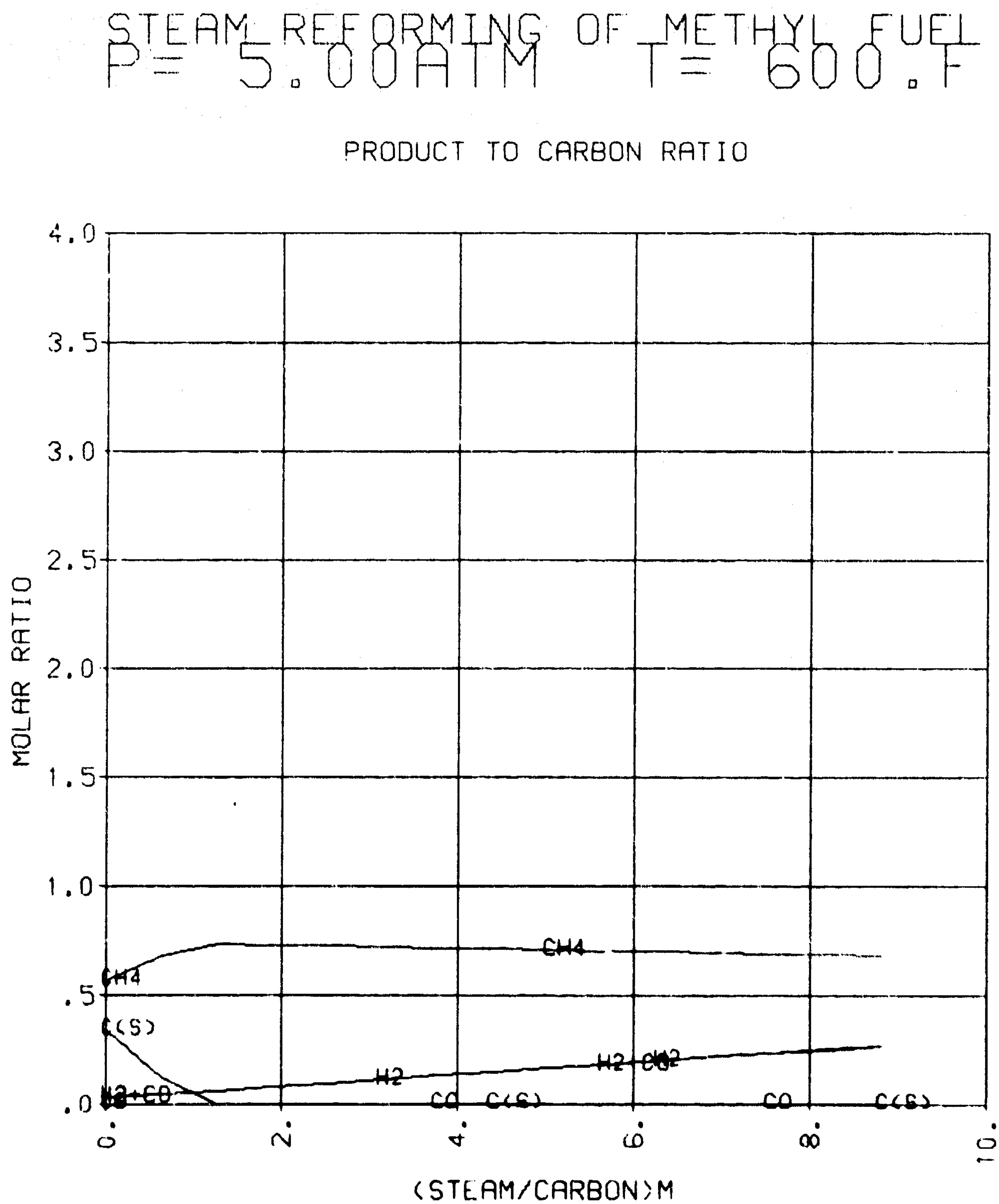

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T= 600.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
CH4
CH4
C(S)
H2
H2+CO2
H2+CO
CO
C(S)
CO
C(S)
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 38.

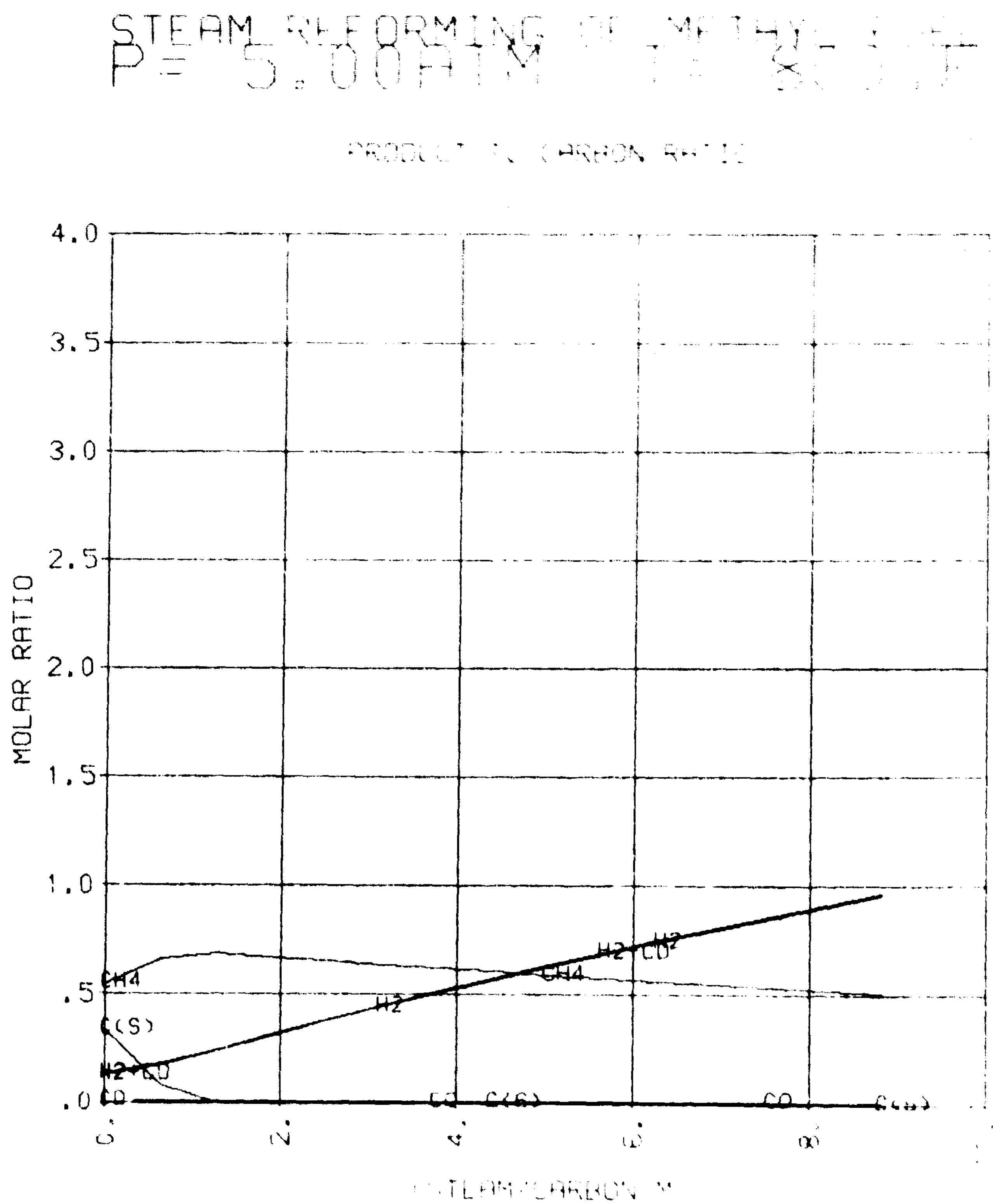

STEAM REFORMING
P= 5.00ATM
MOLAR RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
CH4
C(S)
H2+CO
CO
H2

FIGURE 39.

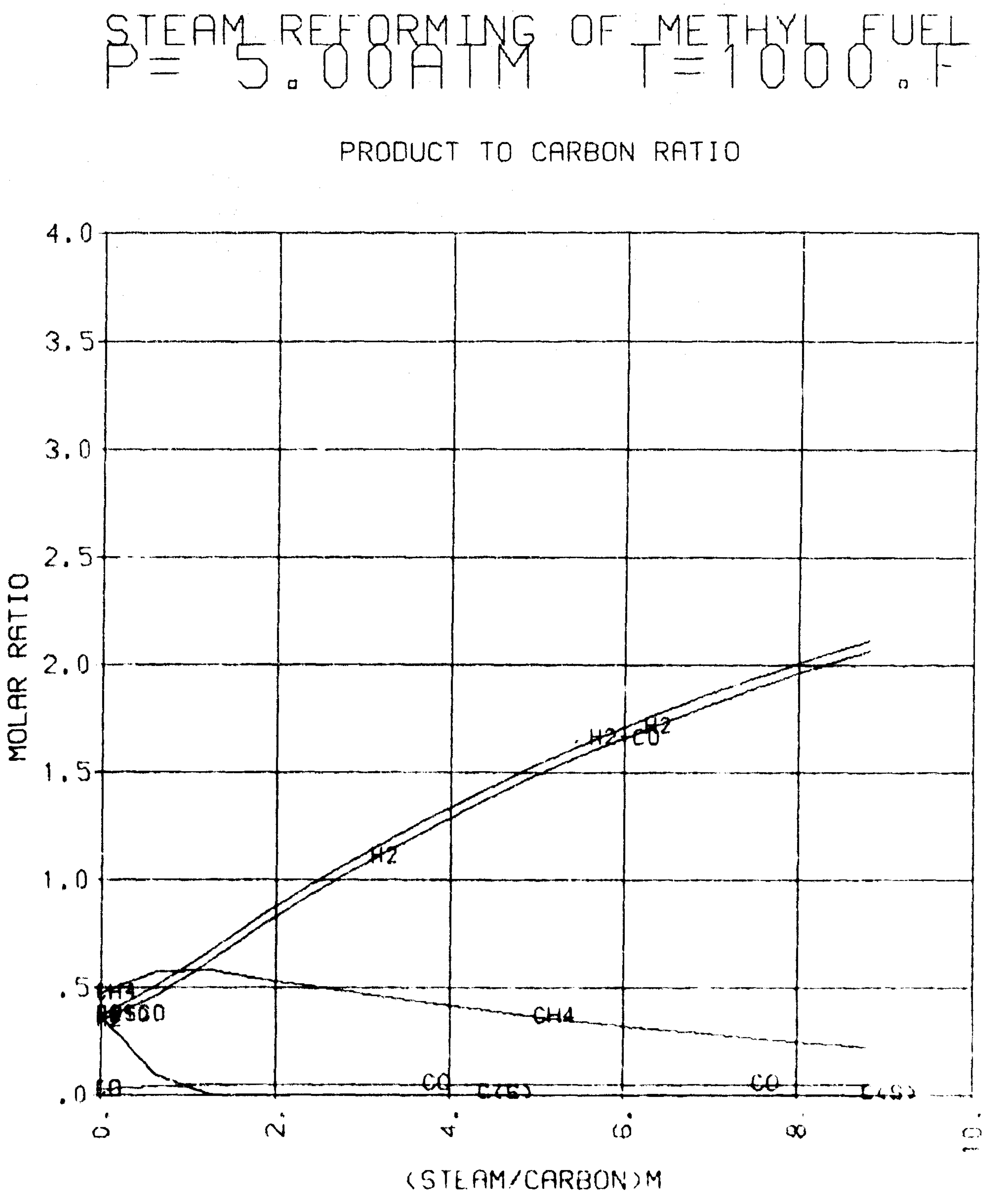

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1000.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
H2
CH4
CH4
CO
CO
CO
C(S)
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

FIGURE 40.

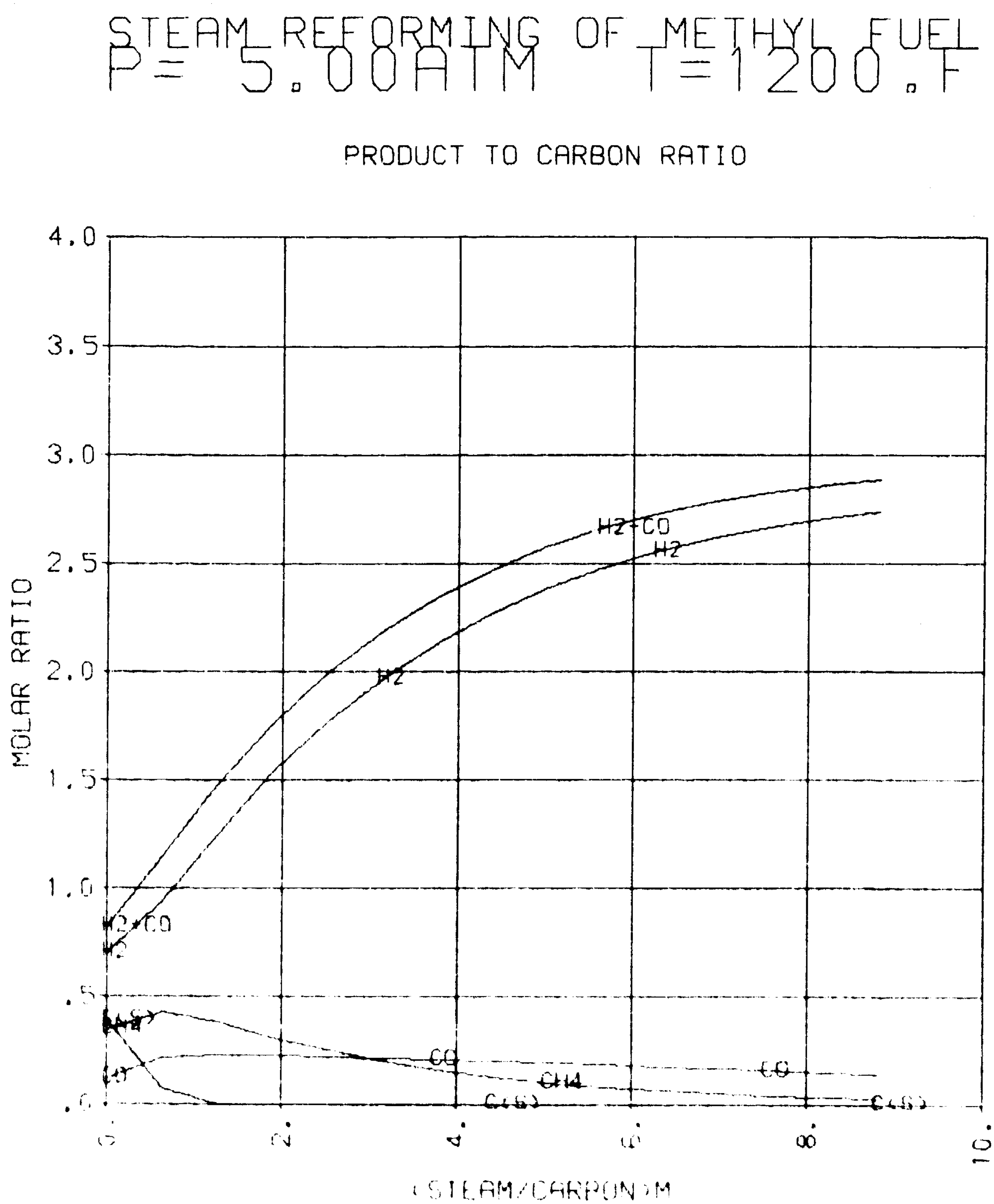

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1200.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
H2
CO
CH4
C(G)
0
2
4
6
8
10.
(STEAM/CARBON)M

FIGURE 41.

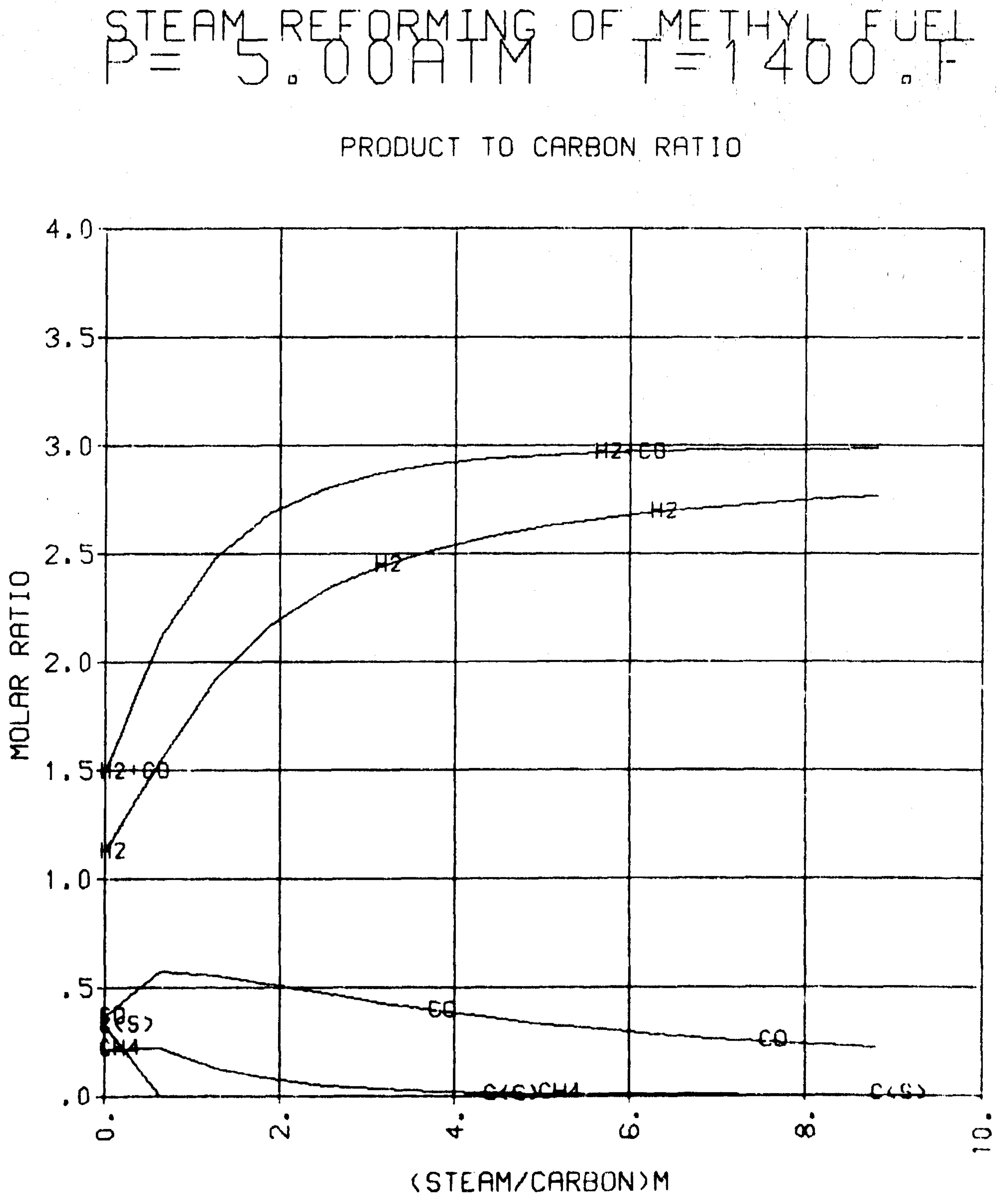
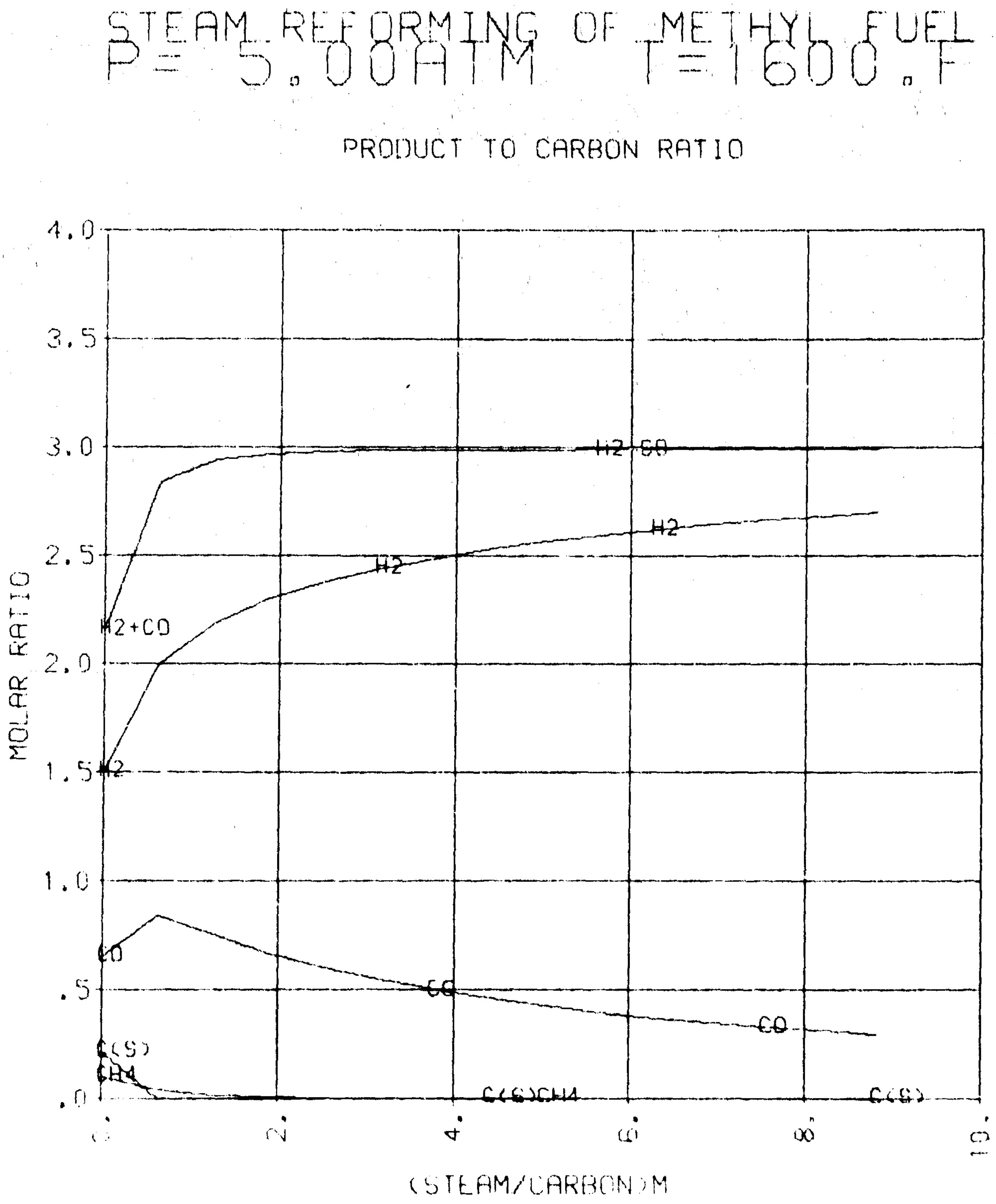

STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1400.F
PRODUCT TO CARBON RATIO
MOLAR RATIO
(STEAM/CARBON)M
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
0.
2.
4.
6.
8.
10.
H2+CO
H2
CO
C(S)
CH4
C(S)CH4

FIGURE 42.



STEAM REFORMING OF METHYL FUEL
P= 5.00ATM T=1600.F
PRODUCT TO CARBON RATIO
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
MOLAR RATIO
H2+CO
H2
CO
C(S)
CH4
C(S)CH4
0.
2.
4.
6.
8.
10.
(STEAM/CARBON)M

TABLE: 1 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE = 400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.22735	.00000	.03611	.32476	.00614	.40563
.50	.78722	.07702	.00000	.07454	.29070	.00635	.55138
1.00	1.57443	.00000	.00000	.08928	.25837	.00664	.64571
1.50	2.36164	.00000	.00000	.07048	.20223	.00700	.72029
2.00	3.14886	.00000	.00000	.05835	.16600	.00721	.76844
2.50	3.93608	.00000	.00000	.04986	.14069	.00735	.80209
3.00	4.72329	.00000	.00000	.04360	.12201	.00745	.82693
3.50	5.51050	.00000	.00000	.03879	.10766	.00752	.84603
4.00	6.29772	.00000	.00000	.03497	.09628	.00757	.86117
5.00	7.87215	.00000	.00000	.02931	.07939	.00764	.88366
6.00	9.44658	.00000	.00000	.02530	.06746	.00768	.89956
7.00	11.02101	.00000	.00000	.02231	.05859	.00770	.91140
8.00	12.59544	.00000	.00000	.02001	.05172	.00771	.92056
9.00	14.16987	.00000	.00000	.01816	.04626	.00771	.92786
10.00	15.74430	.00000	.00000	.01666	.04181	.00771	.93382

TABLE: 2 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE = 600.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.20822	.00020	.05490	.32528	.04324	.36817
.50	.78722	.03610	.00030	.10732	.30851	.04646	.50131
1.00	1.57443	.00000	.00024	.09807	.24170	.05023	.60977
1.50	2.36164	.00000	.00019	.08010	.18619	.05231	.68120
2.00	3.14886	.00000	.00015	.06845	.15054	.05332	.72754
2.50	3.93608	.00000	.00013	.06026	.12572	.05379	.76011
3.00	4.72329	.00000	.00011	.05417	.10746	.05395	.78431
3.50	5.51050	.00000	.00010	.04946	.09347	.05394	.80304
4.00	6.29772	.00000	.00009	.04569	.08242	.05380	.81799
5.00	7.87215	.00000	.00008	.04004	.06608	.05334	.84046
6.00	9.44658	.00000	.00007	.03598	.05461	.05273	.85660
7.00	11.02101	.00000	.00006	.03291	.04613	.05207	.86884
8.00	12.59544	.00000	.00005	.03048	.03962	.05137	.87847
9.00	14.16987	.00000	.00005	.02852	.03447	.05067	.88629
10.00	15.74430	.00000	.00005	.02688	.03030	.04998	.89279

TABLE: 3 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE = 800.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.20944	.00361	.06796	.26360	.15249	.30291
.50	.78722	.03327	.00546	.12763	.25712	.16654	.40998
1.00	1.57443	.00000	.00446	.12088	.19178	.17721	.50567
1.50	2.36164	.00000	.00350	.10508	.13994	.18027	.57121
2.00	3.14886	.00000	.00291	.09436	.10732	.17990	.61552
2.50	3.93608	.00000	.00250	.08647	.08503	.17799	.64801
3.00	4.72329	.00000	.00221	.08035	.06892	.17532	.67320
3.50	5.51050	.00000	.00197	.07541	.05681	.17227	.69354
4.00	6.29772	.00000	.00179	.07129	.04743	.16903	.71047
5.00	7.87215	.00000	.00150	.06470	.03398	.16232	.73750
6.00	9.44658	.00000	.00129	.05956	.02497	.15560	.75858
7.00	11.02101	.00000	.00112	.05535	.01865	.14902	.77587
8.00	12.59544	.00000	.00098	.05176	.01409	.14261	.79055
9.00	14.16987	.00000	.00087	.04863	.01073	.13641	.80335
10.00	15.74430	.00000	.00077	.04585	.00822	.13043	.81472

TABLE: 4 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE =1000.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.21212	.02821	.07160	.15575	.32381	.20851
.50	.78722	.04053	.04185	.12940	.15406	.35539	.27877
1.00	1.57443	.00000	.03586	.13539	.10702	.36860	.35313
1.50	2.36164	.00000	.02773	.12546	.06700	.36305	.41676
2.00	3.14886	.00000	.02237	.11710	.04366	.35090	.46596
2.50	3.93608	.00000	.01847	.10980	.02910	.33596	.50667
3.00	4.72329	.00000	.01546	.10324	.01966	.31986	.54178
3.50	5.51050	.00000	.01307	.09725	.01342	.30345	.57281
4.00	6.29772	.00000	.01113	.09172	.00924	.28727	.60064
5.00	7.87215	.00000	.00823	.08190	.00453	.25686	.64848
6.00	9.44658	.00000	.00624	.07354	.00233	.23012	.68776
7.00	11.02101	.00000	.00486	.06648	.00126	.20730	.72010
8.00	12.59544	.00000	.00386	.06051	.00072	.18801	.74689
9.00	14.16987	.00000	.00314	.05545	.00043	.17171	.76927
10.00	15.74430	.00000	.00260	.05112	.00027	.15784	.78817

TABLE: 5 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE =1200.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.16808	.11580	.05300	.06881	.48654	.10778
.50	.78722	.00000	.15918	.09335	.06160	.53424	.15164
1.00	1.57443	.00000	.10919	.10734	.02342	.51501	.24505
1.50	2.36164	.00000	.07774	.11042	.00983	.47529	.32671
2.00	3.14886	.00000	.05720	.10824	.00451	.43323	.39682
2.50	3.93608	.00000	.04342	.10371	.00225	.39451	.45610
3.00	4.72329	.00000	.03391	.09833	.00121	.36052	.50603
3.50	5.51050	.00000	.02714	.09284	.00069	.33112	.54822
4.00	6.29772	.00000	.02218	.08756	.00042	.30571	.58413
5.00	7.87215	.00000	.01558	.07809	.00017	.26448	.64168
6.00	9.44658	.00000	.01153	.07014	.00008	.23273	.68552
7.00	11.02101	.00000	.00887	.06351	.00004	.20764	.71993
8.00	12.59544	.00000	.00703	.05795	.00002	.18737	.74762
9.00	14.16987	.00000	.00571	.05325	.00001	.17067	.77036
10.00	15.74430	.00000	.00473	.04922	.00001	.15668	.78936

TABLE: 6 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE =1400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.09802	.23299	.01801	.02642	.58857	.03598
.50	.78722	.00000	.22187	.05487	.00664	.59941	.11721
1.00	1.57443	.00000	.14676	.08160	.00156	.53491	.23517
1.50	2.36164	.00000	.10335	.09049	.00055	.47603	.32958
2.00	3.14886	.00000	.07650	.09177	.00024	.42671	.40478
2.50	3.93608	.00000	.05883	.08980	.00012	.38573	.46552
3.00	4.72329	.00000	.04662	.08646	.00006	.35147	.51538
3.50	5.51050	.00000	.03784	.08263	.00004	.32256	.55693
4.00	6.29772	.00000	.03132	.07872	.00002	.29789	.59204
5.00	7.87215	.00000	.02247	.07133	.00001	.25815	.64804
6.00	9.44658	.00000	.01690	.06483	.00000	.22763	.69064
7.00	11.02101	.00000	.01317	.05925	.00000	.20349	.72410
8.00	12.59544	.00000	.01055	.05446	.00000	.18394	.75106
9.00	14.16987	.00000	.00864	.05033	.00000	.16779	.77324
10.00	15.74430	.00000	.00720	.04676	.00000	.15424	.79180

TABLE: 7 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =1.0: TEMPERATURE =1600.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.06969	.28146	.00285	.00907	.62913	.00779
.50	.78722	.00000	.23911	.04040	.00036	.59678	.12335
1.00	1.57443	.00000	.16463	.06454	.00008	.52092	.24984
1.50	2.36164	.00000	.12037	.07378	.00003	.46049	.34533
2.00	3.14886	.00000	.09191	.07651	.00001	.41197	.41959
2.50	3.93608	.00000	.07250	.07621	.00001	.37241	.47888
3.00	4.72329	.00000	.05867	.07445	.00000	.33962	.52725
3.50	5.51050	.00000	.04846	.07203	.00000	.31205	.56745
4.00	6.29772	.00000	.04071	.06935	.00000	.28857	.60137
5.00	7.87215	.00000	.02991	.06390	.00000	.25075	.65545
6.00	9.44658	.00000	.02290	.05883	.00000	.22164	.69662
7.00	11.02101	.00000	.01810	.05432	.00000	.19856	.72902
8.00	12.59544	.00000	.01467	.05034	.00000	.17982	.75517
9.00	14.16987	.00000	.01212	.04685	.00000	.16431	.77672
10.00	15.74430	.00000	.01019	.04377	.00000	.15125	.79479

TABLE: 8 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE = 400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.22679	.00000	.03610	.32674	.00356	.40681
.50	.78722	.07624	.00000	.07452	.29252	.00368	.55303
1.00	1.57443	.00000	.00000	.08870	.25943	.00385	.64801
1.50	2.36164	.00000	.00000	.06985	.20326	.00406	.72283
2.00	3.14886	.00000	.00000	.05768	.16701	.00419	.77112
2.50	3.93608	.00000	.00000	.04917	.14168	.00428	.80487
3.00	4.72329	.00000	.00000	.04289	.12298	.00434	.82979
3.50	5.51050	.00000	.00000	.03806	.10861	.00438	.84894
4.00	6.29772	.00000	.00000	.03424	.09723	.00441	.86412
5.00	7.87215	.00000	.00000	.02856	.08032	.00446	.88666
6.00	9.44658	.00000	.00000	.02454	.06837	.00449	.90260
7.00	11.02101	.00000	.00000	.02155	.05948	.00451	.91446
8.00	12.59544	.00000	.00000	.01924	.05261	.00452	.92363
9.00	14.16987	.00000	.00000	.01740	.04713	.00453	.93094
10.00	15.74430	.00000	.00000	.01589	.04267	.00453	.93690

TABLE: 9 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE = 600.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.20430	.00011	.05496	.33900	.02555	.37607
.50	.78722	.03003	.00017	.10760	.32194	.02749	.51277
1.00	1.57443	.00000	.00014	.09397	.24945	.02994	.62650
1.50	2.36164	.00000	.00010	.07565	.19361	.03135	.69929
2.00	3.14886	.00000	.00008	.06380	.15766	.03210	.74636
2.50	3.93608	.00000	.00007	.05550	.13258	.03253	.77933
3.00	4.72329	.00000	.00006	.04935	.11409	.03276	.80373
3.50	5.51050	.00000	.00005	.04462	.09991	.03288	.82254
4.00	6.29772	.00000	.00005	.04085	.08868	.03292	.83750
5.00	7.87215	.00000	.00004	.03523	.07205	.03286	.85981
6.00	9.44658	.00000	.00004	.03123	.06033	.03270	.87571
7.00	11.02101	.00000	.00003	.02823	.05163	.03247	.88763
8.00	12.59544	.00000	.00003	.02589	.04493	.03222	.89694
9.00	14.16987	.00000	.00003	.02401	.03961	.03194	.90441
10.00	15.74430	.00000	.00002	.02246	.03529	.03166	.91057

TABLE: 10 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE = 800.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.19781	.00211	.06856	.30728	.09575	.32850
.50	.78722	.01422	.00321	.12964	.30090	.10503	.44700
1.00	1.57443	.00000	.00235	.10945	.21679	.11359	.55783
1.50	2.36164	.00000	.00182	.09271	.16291	.11676	.62580
2.00	3.14886	.00000	.00151	.08164	.12860	.11761	.67064
2.50	3.93608	.00000	.00130	.07371	.10490	.11737	.70271
3.00	4.72329	.00000	.00114	.06771	.08759	.11657	.72698
3.50	5.51050	.00000	.00103	.06298	.07443	.11545	.74611
4.00	6.29772	.00000	.00093	.05913	.06410	.11416	.76167
5.00	7.87215	.00000	.00079	.05320	.04901	.11133	.78567
6.00	9.44656	.00000	.00069	.04877	.03858	.10838	.80358
7.00	11.02101	.00000	.00062	.04528	.03101	.10545	.81764
8.00	12.59544	.00000	.00055	.04244	.02530	.10257	.82913
9.00	14.16987	.00000	.00050	.04005	.02088	.09977	.83860
10.00	15.74430	.00000	.00046	.03799	.01739	.09705	.84712

TABLE: 11 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE =1000.OF

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.20096	.01669	.07416	.22589	.22673	.25556
.50	.78722	.01990	.02503	.13592	.22424	.25019	.34471
1.00	1.57443	.00000	.01938	.12679	.15334	.26334	.43716
1.50	2.36164	.00000	.01525	.11392	.10628	.26407	.50049
2.00	3.14886	.00000	.01265	.10455	.07726	.26008	.54546
2.50	3.93608	.00000	.01081	.09723	.05789	.25408	.57999
3.00	4.72329	.00000	.00941	.09125	.04425	.24713	.60796
3.50	5.51050	.00000	.00830	.08616	.03430	.23974	.63149
4.00	6.29772	.00000	.00739	.08173	.02686	.23217	.65186
5.00	7.87215	.00000	.00595	.07421	.01679	.21697	.68608
6.00	9.44658	.00000	.00488	.06792	.01068	.20216	.71436
7.00	11.02101	.00000	.00404	.06249	.00689	.18806	.73852
8.00	12.59544	.00000	.00337	.05772	.00450	.17488	.75953
9.00	14.16987	.00000	.00284	.05350	.00298	.16273	.77795
10.00	15.74430	.00000	.00241	.04976	.00201	.15166	.79417

TABLE: 12 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE =1200.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.18146	.07306	.06433	.13160	.38533	.16421
.50	.78722	.00000	.10730	.11497	.13027	.42636	.22111
1.00	1.57443	.00000	.07714	.11513	.06819	.42937	.31016
1.50	2.36164	.00000	.05912	.11165	.03826	.41324	.37773
2.00	3.14886	.00000	.04668	.10700	.02225	.39068	.43340
2.50	3.93608	.00000	.03752	.10187	.01326	.36617	.48118
3.00	4.72329	.00000	.03057	.09662	.00809	.34182	.52289
3.50	5.51050	.00000	.02521	.09145	.00505	.31874	.55954
4.00	6.29772	.00000	.02104	.08649	.00324	.29742	.59180
5.00	7.87215	.00000	.01514	.07749	.00144	.26057	.64535
6.00	9.44658	.00000	.01134	.06981	.00070	.23074	.68741
7.00	11.02101	.00000	.00878	.06332	.00037	.20656	.72097
8.00	12.59544	.00000	.00699	.05784	.00021	.18674	.74823
9.00	14.16987	.00000	.00569	.05317	.00013	.17029	.77073
10.00	15.74430	.00000	.00472	.04917	.00008	.15644	.78959

TABLE: 13 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE =1400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.12228	.18209	.03392	.06385	.52110	.07676
.50	.78722	.00000	.19905	.06525	.03486	.55657	.14427
1.00	1.57443	.00000	.13878	.08429	.01133	.51720	.24840
1.50	2.36164	.00000	.10030	.09113	.00448	.46792	.33616
2.00	3.14886	.00000	.07520	.09188	.00204	.42262	.40826
2.50	3.93608	.00000	.05823	.08976	.00103	.38350	.46748
3.00	4.72329	.00000	.04632	.08640	.00056	.35018	.51654
3.50	5.51050	.00000	.03768	.08258	.00033	.32177	.55765
4.00	6.29772	.00000	.03123	.07868	.00020	.29738	.59251
5.00	7.87215	.00000	.02243	.07130	.00009	.25792	.64825
6.00	9.44658	.00000	.01688	.06482	.00004	.22751	.69075
7.00	11.02101	.00000	.01316	.05924	.00002	.20342	.72416
8.00	12.59544	.00000	.01054	.05445	.00001	.18390	.75109
9.00	14.16987	.00000	.00863	.05033	.00001	.16777	.77326
10.00	15.74430	.00000	.00720	.04676	.00000	.15422	.79181

TABLE: 14 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =3.0: TEMPERATURE =1600.OF

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.07425	.26736	.00775	.02520	.60399	.02143
.50	.78722	.00000	.23707	.04124	.00307	.59251	.12611
1.00	1.57443	.00000	.16411	.06471	.00072	.51975	.25071
1.50	2.36164	.00000	.12018	.07383	.00027	.46001	.34572
2.00	3.14886	.00000	.09183	.07652	.00012	.41174	.41979
2.50	3.93608	.00000	.07246	.07621	.00006	.37228	.47899
3.00	4.72329	.00000	.05865	.07445	.00003	.33954	.52732
3.50	5.51050	.00000	.04845	.07203	.00002	.31200	.56749
4.00	6.29772	.00000	.04070	.06935	.00001	.28854	.60140
5.00	7.87215	.00000	.02990	.06390	.00001	.25073	.65546
6.00	9.44658	.00000	.02290	.05883	.00000	.22163	.69663
7.00	11.02101	.00000	.01810	.05432	.00000	.19856	.72903
8.00	12.59544	.00000	.01467	.05034	.00000	.17982	.75517
9.00	14.16987	.00000	.01212	.04685	.00000	.16431	.77672
10.00	15.74430	.00000	.01019	.04377	.00000	.15125	.79479

TABLE: 15 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE = 400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.22662	.00000	.03610	.32735	.00276	.40717
.50	.78722	.07600	.00000	.07452	.29308	.00285	.55355
1.00	1.57443	.00000	.00000	.08853	.25976	.00299	.64873
1.50	2.36164	.00000	.00000	.06965	.20358	.00315	.72361
2.00	3.14886	.00000	.00000	.05747	.16733	.00325	.77195
2.50	3.93608	.00000	.00000	.04895	.14199	.00332	.80574
3.00	4.72329	.00000	.00000	.04267	.12329	.00337	.83068
3.50	5.51050	.00000	.00000	.03784	.10891	.00340	.84985
4.00	6.29772	.00000	.00000	.03401	.09752	.00343	.86504
5.00	7.87215	.00000	.00000	.02832	.08061	.00347	.88760
6.00	9.44658	.00000	.00000	.02430	.06866	.00349	.90355
7.00	11.02101	.00000	.00000	.02131	.05976	.00351	.91542
8.00	12.59544	.00000	.00000	.01900	.05288	.00352	.92460
9.00	14.16987	.00000	.00000	.01715	.04741	.00353	.93191
10.00	15.74430	.00000	.00000	.01565	.04294	.00353	.93787

TABLE: 16 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE = 600.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.20305	.00009	.05499	.34336	.01993	.37858
.50	.78722	.02808	.00014	.10769	.32622	.02146	.51641
1.00	1.57443	.00000	.00010	.09266	.25194	.02343	.63186
1.50	2.36164	.00000	.00008	.07421	.19601	.02458	.70513
2.00	3.14886	.00000	.00006	.06229	.15997	.02521	.75247
2.50	3.93608	.00000	.00005	.05394	.13481	.02558	.78561
3.00	4.72329	.00000	.00005	.04777	.11627	.02581	.81011
3.50	5.51050	.00000	.00004	.04302	.10203	.02594	.82897
4.00	6.29772	.00000	.00004	.03925	.09075	.02601	.84396
5.00	7.87215	.00000	.00003	.03363	.07404	.02603	.86627
6.00	9.44658	.00000	.00003	.02963	.06225	.02596	.88213
7.00	11.02101	.00000	.00002	.02665	.05350	.02584	.89400
8.00	12.59544	.00000	.00002	.02432	.04674	.02569	.90323
9.00	14.16987	.00000	.00002	.02246	.04137	.02552	.91063
10.00	15.74430	.00000	.00002	.02093	.03701	.02535	.91670

TABLE: 17 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE = 800.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.19363	.00164	.06884	.32249	.07618	.33722
.50	.78722	.00733	.00250	.13046	.31629	.08370	.45972
1.00	1.57443	.00000	.00176	.10530	.22554	.09119	.57622
1.50	2.36164	.00000	.00136	.08820	.17105	.09413	.64527
2.00	3.14886	.00000	.00112	.07697	.13623	.09517	.69051
2.50	3.93608	.00000	.00096	.06899	.11211	.09530	.72264
3.00	4.72329	.00000	.00084	.06299	.09443	.09495	.74678
3.50	5.51050	.00000	.00076	.05830	.08095	.09432	.76567
4.00	6.29772	.00000	.00069	.05451	.07035	.09353	.78092
5.00	7.87215	.00000	.00059	.04672	.05478	.09170	.80422
6.00	9.44658	.00000	.00051	.04446	.04395	.08973	.82135
7.00	11.02101	.00000	.00046	.04116	.03602	.08774	.83463
8.00	12.59544	.00000	.00041	.03850	.02999	.08577	.84532
9.00	14.16987	.00000	.00038	.03629	.02528	.08384	.85420
10.00	15.74430	.00000	.00035	.03442	.02152	.08197	.86175

TABLE: 18 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE =1000.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.19494	.01308	.07535	.25534	.18743	.27386
.50	.78722	.00921	.01970	.13878	.25410	.20742	.37078
1.00	1.57443	.00000	.01442	.12183	.17164	.22019	.47192
1.50	2.36164	.00000	.01136	.10796	.12238	.22225	.53605
2.00	3.14886	.00000	.00946	.09821	.09163	.22028	.58042
2.50	3.93608	.00000	.00813	.09083	.07081	.21656	.61367
3.00	4.72329	.00000	.00714	.08495	.05593	.21200	.63998
3.50	5.51050	.00000	.00636	.08009	.04487	.20704	.66165
4.00	6.29772	.00000	.00572	.07594	.03642	.20189	.68004
5.00	7.87215	.00000	.00473	.06912	.02457	.19144	.71015
6.00	9.44658	.00000	.00398	.06359	.01693	.18111	.73439
7.00	11.02101	.00000	.00339	.05891	.01183	.17109	.75478
8.00	12.59544	.00000	.00291	.05484	.00834	.16147	.77244
9.00	14.16987	.00000	.00251	.05123	.00593	.15231	.78802
10.00	15.74430	.00000	.00218	.04799	.00424	.14366	.80192

TABLE: 19 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE =1200.0F

$(H_2O/F)_W$	$(H_2O/C)_M$	C(S)	CO	CO_2	CH_4	H_2	H_2O
.00	.00000	.18211	.05840	.06855	.16579	.33489	.19026
.50	.78722	.00000	.08536	.12233	.16332	.37139	.25760
1.00	1.57443	.00000	.06170	.11712	.09305	.37949	.34865
1.50	2.36164	.00000	.04821	.11102	.05714	.37057	.41306
2.00	3.14886	.00000	.03906	.10518	.03648	.35570	.46358
2.50	3.93608	.00000	.03229	.09967	.02383	.33851	.50569
3.00	4.72329	.00000	.02704	.09448	.01582	.32059	.54207
3.50	5.51050	.00000	.02286	.08957	.01063	.30279	.57415
4.00	6.29772	.00000	.01948	.08493	.00724	.28560	.60274
5.00	7.87215	.00000	.01445	.07651	.00350	.25416	.65138
6.00	9.44658	.00000	.01102	.06921	.00180	.22720	.69077
7.00	11.02101	.00000	.00862	.06296	.00098	.20454	.72290
8.00	12.59544	.00000	.00690	.05761	.00057	.18554	.74938
9.00	14.16987	.00000	.00564	.05303	.00034	.16954	.77145
10.00	15.74430	.00000	.00469	.04908	.00022	.15596	.79006

TABLE: 20 MAIN PRODUCT COMPOSITION OF STEAM REFORMING METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0: TEMPERATURE =1400.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.13243	.15618	.04208	.09032	.47729	.10169
.50	.78722	.00000	.17927	.07395	.06000	.51786	.14892
1.00	1.57443	.00000	.12879	.08750	.02384	.49430	.26556
1.50	2.36164	.00000	.09564	.09205	.01060	.45522	.34649
2.00	3.14886	.00000	.07299	.09203	.00515	.41553	.41430
2.50	3.93608	.00000	.05713	.08969	.00270	.37942	.47107
3.00	4.72329	.00000	.04574	.08628	.00151	.34773	.51874
3.50	5.51050	.00000	.03735	.08247	.00089	.32024	.55905
4.00	6.29772	.00000	.03104	.07859	.00055	.29640	.59342
5.00	7.87215	.00000	.02236	.07125	.00024	.25747	.64868
6.00	9.44658	.00000	.01685	.06479	.00012	.22728	.69096
7.00	11.02101	.00000	.01314	.05922	.00006	.20330	.72428
8.00	12.59544	.00000	.01053	.05444	.00004	.18383	.75116
9.00	14.16987	.00000	.00863	.05032	.00002	.16772	.77330
10.00	15.74430	.00000	.00720	.04675	.00001	.15420	.79184

TABLE: 21 MAIN PRODUCT COMPOSITION OF STEAM REFORMING
METHANOL AND INDOLINE (90/10 WEIGHT RATIO)

PRESSURE =5.0; TEMPERATURE =1600.0F

(H2O/F)W	(H2O/C)M	C(S)	CO	CO2	CH4	H2	H2O
.00	.00000	.07786	.25564	.01186	.03920	.58238	.03305
.50	.78722	.00000	.23352	.04271	.00780	.58507	.13091
1.00	1.57443	.00000	.16312	.06503	.00195	.51750	.25239
1.50	2.36164	.00000	.11981	.07392	.00073	.45906	.34648
2.00	3.14886	.00000	.09166	.07655	.00033	.41127	.42019
2.50	3.93608	.00000	.07238	.07621	.00017	.37202	.47922
3.00	4.72329	.00000	.05861	.07445	.00009	.33939	.52746
3.50	5.51050	.00000	.04843	.07203	.00006	.31191	.56758
4.00	6.29772	.00000	.04069	.06934	.00004	.28848	.60145
5.00	7.87215	.00000	.02990	.06390	.00002	.25070	.65549
6.00	9.44658	.00000	.02290	.05883	.00001	.22162	.69665
7.00	11.02101	.00000	.01810	.05432	.00000	.19855	.72903
8.00	12.59544	.00000	.01466	.05034	.00000	.17982	.75518
9.00	14.16987	.00000	.01212	.04685	.00000	.16430	.77673
10.00	15.74430	.00000	.01019	.04377	.00000	.15125	.79479

TABLE: 22 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE = 400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.01044	.00000	.55210	.38650	.01045
.50	.78722	.01436	.00001	.65730	.17415	.01437
1.00	1.57443	.01910	.00001	.74319	.00000	.01912
1.50	2.36164	.02567	.00001	.74155	.00000	.02568
2.00	3.14886	.03216	.00001	.73992	.00000	.03217
2.50	3.93608	.03860	.00001	.73831	.00000	.03861
3.00	4.72329	.04500	.00001	.73671	.00000	.04501
3.50	5.51050	.05137	.00001	.73512	.00000	.05138
4.00	6.29772	.05771	.00001	.73354	.00000	.05772
5.00	7.87215	.07030	.00001	.73039	.00000	.07031
6.00	9.44658	.08279	.00001	.72727	.00000	.08280
7.00	11.02101	.09518	.00001	.72417	.00000	.09519
8.00	12.59544	.10747	.00001	.72109	.00000	.10749
9.00	14.16987	.11968	.00001	.71804	.00000	.11969
10.00	15.74430	.13180	.00001	.71501	.00000	.13181

TABLE: 23 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE = 600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.07347	.00033	.55264	.35376	.07380
.50	.78722	.10275	.00067	.68220	.07983	.10341
1.00	1.57443	.14772	.00072	.71086	.00000	.14844
1.50	2.36164	.19631	.00070	.69871	.00000	.19701
2.00	3.14886	.24332	.00069	.68696	.00000	.24401
2.50	3.93608	.28902	.00069	.67554	.00000	.28972
3.00	4.72329	.33358	.00070	.66440	.00000	.33428
3.50	5.51050	.37710	.00070	.65351	.00000	.37781
4.00	6.29772	.41968	.00071	.64287	.00000	.42039
5.00	7.87215	.50223	.00072	.62223	.00000	.50295
6.00	9.44658	.58164	.00074	.60237	.00000	.58238
7.00	11.02101	.65823	.00075	.58322	.00000	.65899
8.00	12.59544	.73224	.00077	.56472	.00000	.73301
9.00	14.16987	.80385	.00078	.54681	.00000	.80464
10.00	15.74430	.87324	.00080	.52946	.00000	.87404

TABLE: 24 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE = 800.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.27999	.00662	.48403	.38457	.28662
.50	.78722	.39325	.01290	.60715	.07856	.40616
1.00	1.57443	.55879	.01408	.60475	.00000	.57287
1.50	2.36164	.72538	.01407	.56310	.00000	.73945
2.00	3.14886	.87935	.01421	.52458	.00000	.89355
2.50	3.93608	1.02290	.01439	.48865	.00000	1.03729
3.00	4.72329	1.15739	.01456	.45498	.00000	1.17196
3.50	5.51050	1.28377	.01471	.42335	.00000	1.29848
4.00	6.29772	1.40270	.01483	.39358	.00000	1.41754
5.00	7.87215	1.62027	.01498	.33915	.00000	1.63525
6.00	9.44658	1.81320	.01501	.29091	.00000	1.82821
7.00	11.02101	1.98374	.01492	.24830	.00000	1.99865
8.00	12.59544	2.13367	.01472	.21087	.00000	2.14840
9.00	14.16987	2.26458	.01445	.17821	.00000	2.27903
10.00	15.74430	2.37797	.01411	.14995	.00000	2.39208

TABLE: 25 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE =1000.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.69237	.06032	.33302	.45355	.75269
.50	.78722	.97144	.11440	.42111	.11079	1.08584
1.00	1.57443	1.32463	.12885	.38460	.00000	1.45348
1.50	2.36164	1.64875	.12593	.30430	.00000	1.77468
2.00	3.14886	1.91604	.12217	.23841	.00000	2.03821
2.50	3.93608	2.13491	.11738	.18489	.00000	2.25229
3.00	4.72329	2.31176	.11177	.14209	.00000	2.42352
3.50	5.51050	2.45244	.10563	.10845	.00000	2.55807
4.00	6.29772	2.56269	.09929	.08247	.00000	2.66197
5.00	7.87215	2.71362	.08695	.04782	.00000	2.80057
6.00	9.44658	2.80242	.07603	.02835	.00000	2.87845
7.00	11.02101	2.85533	.06688	.01741	.00000	2.92222
8.00	12.59544	2.88803	.05937	.01112	.00000	2.94740
9.00	14.16987	2.90919	.05320	.00737	.00000	2.96239
10.00	15.74430	2.92355	.04811	.00505	.00000	2.97166

TABLE: 26 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE =1200.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.19934	.28544	.16962	.41431	1.48477
.50	.78722	1.70074	.50673	.19610	.00000	2.20748
1.00	1.57443	2.14635	.45504	.09762	.00000	2.60139
1.50	2.36164	2.40056	.39266	.04966	.00000	2.79322
2.00	3.14886	2.54916	.33655	.02654	.00000	2.88571
2.50	3.93608	2.64097	.29066	.01506	.00000	2.93163
3.00	4.72329	2.70155	.25409	.00906	.00000	2.95564
3.50	5.51050	2.74403	.22491	.00573	.00000	2.96894
4.00	6.29772	2.77536	.20135	.00379	.00000	2.97671
5.00	7.87215	2.81849	.16601	.00184	.00000	2.98450
6.00	9.44658	2.84689	.14099	.00100	.00000	2.98788
7.00	11.02101	2.86710	.12242	.00059	.00000	2.98952
8.00	12.59544	2.88226	.10814	.00037	.00000	2.99040
9.00	14.16987	2.89408	.09682	.00024	.00000	2.99090
10.00	15.74430	2.90357	.08764	.00016	.00000	2.99121

TABLE: 27 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE =1400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.56765	.62057	.07037	.26107	2.18822
.50	.78722	2.11521	.78296	.02343	.00000	2.89817
1.00	1.57443	2.32648	.63833	.00676	.00000	2.96481
1.50	2.36164	2.44887	.53166	.00283	.00000	2.98053
2.00	3.14886	2.53222	.45397	.00142	.00000	2.98619
2.50	3.93608	2.59316	.39553	.00079	.00000	2.98869
3.00	4.72329	2.63978	.35017	.00048	.00000	2.98995
3.50	5.51050	2.67662	.31402	.00031	.00000	2.99063
4.00	6.29772	2.70648	.28456	.00021	.00000	2.99104
5.00	7.87215	2.75193	.23952	.00010	.00000	2.99145
6.00	9.44658	2.78491	.20673	.00006	.00000	2.99164
7.00	11.02101	2.80992	.18181	.00003	.00000	2.99173
8.00	12.59544	2.82954	.16223	.00002	.00000	2.99178
9.00	14.16987	2.84535	.14646	.00001	.00000	2.99181
10.00	15.74430	2.85835	.13347	.00001	.00000	2.99182

TABLE: 28 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =1.0: TEMPERATURE =1600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.73282	.77521	.02498	.19195	2.50803
.50	.78722	2.13235	.85437	.00128	.00000	2.98673
1.00	1.57443	2.27232	.71813	.00035	.00000	2.99044
1.50	2.36164	2.37137	.61988	.00015	.00000	2.99125
2.00	3.14886	2.44589	.54566	.00008	.00000	2.99155
2.50	3.93608	2.50415	.48753	.00005	.00000	2.99168
3.00	4.72329	2.55103	.44072	.00003	.00000	2.99175
3.50	5.51050	2.58960	.40219	.00002	.00000	2.99179
4.00	6.29772	2.62191	.36990	.00001	.00000	2.99181
5.00	7.87215	2.67302	.31882	.00001	.00000	2.99184
6.00	9.44658	2.71166	.28019	.00000	.00000	2.99185
7.00	11.02101	2.74192	.24994	.00000	.00000	2.99185
8.00	12.59544	2.76626	.22560	.00000	.00000	2.99186
9.00	14.16987	2.78627	.20560	.00000	.00000	2.99186
10.00	15.74430	2.80301	.18886	.00000	.00000	2.99186

TABLE: 29 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE = 400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.00604	.00000	.55414	.38463	.00604
.50	.78722	.00830	.00001	.65989	.17199	.00831
1.00	1.57443	.01106	.00001	.74520	.00000	.01107
1.50	2.36164	.01487	.00001	.74425	.00000	.01488
2.00	3.14886	.01865	.00001	.74330	.00000	.01866
2.50	3.93608	.02241	.00001	.74236	.00000	.02241
3.00	4.72329	.02614	.00001	.74143	.00000	.02615
3.50	5.51050	.02987	.00001	.74050	.00000	.02987
4.00	6.29772	.03358	.00001	.73957	.00000	.03359
5.00	7.87215	.04097	.00001	.73772	.00000	.04098
6.00	9.44658	.04833	.00001	.73588	.00000	.04834
7.00	11.02101	.05565	.00001	.73405	.00000	.05565
8.00	12.59544	.06293	.00001	.73223	.00000	.06294
9.00	14.16987	.07018	.00001	.73042	.00000	.07019
10.00	15.74430	.07740	.00001	.72862	.00000	.07740

TABLE: 30 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE = 600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.04270	.00019	.56653	.34143	.04289
.50	.78722	.05979	.00038	.70026	.06532	.06017
1.00	1.57443	.08715	.00040	.72608	.00000	.08755
1.50	2.36164	.11638	.00038	.71878	.00000	.11676
2.00	3.14886	.14491	.00037	.71165	.00000	.14528
2.50	3.93608	.17288	.00037	.70465	.00000	.17326
3.00	4.72329	.20037	.00037	.69778	.00000	.20075
3.50	5.51050	.22742	.00037	.69102	.00000	.22780
4.00	6.29772	.25406	.00038	.68436	.00000	.25444
5.00	7.87215	.30620	.00038	.67132	.00000	.30658
6.00	9.44658	.35695	.00039	.65863	.00000	.35734
7.00	11.02101	.40643	.00039	.64626	.00000	.40682
8.00	12.59544	.45473	.00040	.63418	.00000	.45513
9.00	14.16987	.50193	.00040	.62238	.00000	.50234
10.00	15.74430	.54810	.00041	.61084	.00000	.54851

TABLE: 31 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE = 800.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.16630	.00366	.53370	.34356	.16996
.50	.78722	.23446	.00717	.67169	.03174	.24163
1.00	1.57443	.34568	.00715	.65976	.00000	.35283
1.50	2.36164	.45354	.00708	.63281	.00000	.46063
2.00	3.14886	.55542	.00713	.60733	.00000	.56255
2.50	3.93608	.65238	.00721	.58307	.00000	.65959
3.00	4.72329	.74507	.00731	.55987	.00000	.75239
3.50	5.51050	.83395	.00742	.53762	.00000	.84137
4.00	6.29772	.91937	.00752	.51624	.00000	.92689
5.00	7.87215	1.08081	.00771	.47584	.00000	1.08852
6.00	9.44658	1.23101	.00787	.43825	.00000	1.23888
7.00	11.02101	1.37108	.00800	.40320	.00000	1.37909
8.00	12.59544	1.50187	.00810	.37047	.00000	1.50997
9.00	14.16987	1.62401	.00817	.33992	.00000	1.63218
10.00	15.74430	1.73803	.00822	.31141	.00000	1.74624

TABLE: 32 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE =1000.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.43796	.03225	.43633	.38818	.47020
.50	.78722	.61762	.06179	.55355	.04912	.67941
1.00	1.57443	.87928	.06470	.51197	.00000	.94398
1.50	2.36164	1.12156	.06477	.45138	.00000	1.18633
2.00	3.14886	1.33748	.06504	.39734	.00000	1.40252
2.50	3.93608	1.53123	.06513	.34888	.00000	1.59636
3.00	4.72329	1.70540	.06494	.30538	.00000	1.77034
3.50	5.51050	1.86182	.06445	.26640	.00000	1.92628
4.00	6.29772	2.00191	.06368	.23157	.00000	2.06559
5.00	7.87215	2.23776	.06141	.17317	.00000	2.29918
6.00	9.44658	2.42157	.05842	.12797	.00000	2.47999
7.00	11.02101	2.56163	.05499	.09381	.00000	2.61662
8.00	12.59544	2.66620	.05141	.06856	.00000	2.71761
9.00	14.16987	2.74312	.04787	.05022	.00000	2.79099
10.00	15.74430	2.79927	.04450	.03702	.00000	2.84377

TABLE: 33 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE =1200.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.85542	.16220	.29214	.40284	1.01762
.50	.78722	1.20943	.30436	.36952	.00000	1.51379
1.00	1.57443	1.64846	.29617	.26181	.00000	1.94463
1.50	2.36164	1.97694	.28283	.18302	.00000	2.25978
2.00	3.14886	2.22072	.26535	.12645	.00000	2.48607
2.50	3.93608	2.39863	.24579	.08686	.00000	2.64442
3.00	4.72329	2.52674	.22598	.05979	.00000	2.75273
3.50	5.51050	2.61864	.20715	.04152	.00000	2.82578
4.00	6.29772	2.68495	.18993	.02925	.00000	2.87488
5.00	7.87215	2.76975	.16098	.01528	.00000	2.93073
6.00	9.44658	2.81901	.13856	.00858	.00000	2.95756
7.00	11.02101	2.85019	.12115	.00513	.00000	2.97135
8.00	12.59544	2.87148	.10743	.00324	.00000	2.97891
9.00	14.16987	2.88691	.09640	.00214	.00000	2.98331
10.00	15.74430	2.89863	.08737	.00147	.00000	2.98600

TABLE: 34 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =3.0: TEMPERATURE =1400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.29581	.45280	.15878	.30408	1.74861
.50	.78722	1.86039	.66536	.11653	.00000	2.52576
1.00	1.57443	2.20649	.59207	.04833	.00000	2.79856
1.50	2.36164	2.38842	.51198	.02287	.00000	2.90040
2.00	3.14886	2.49899	.44469	.01205	.00000	2.94367
2.50	3.93608	2.57349	.39074	.00691	.00000	2.96423
3.00	4.72329	2.62742	.34751	.00423	.00000	2.97493
3.50	5.51050	2.66847	.31245	.00274	.00000	2.98092
4.00	6.29772	2.70089	.28359	.00184	.00000	2.98449
5.00	7.87215	2.74906	.23910	.00093	.00000	2.98816
6.00	9.44658	2.78328	.20652	.00052	.00000	2.98980
7.00	11.02101	2.80893	.18170	.00031	.00000	2.99063
8.00	12.59544	2.82890	.16217	.00020	.00000	2.99108
9.00	14.16987	2.84492	.14642	.00013	.00000	2.99134
10.00	15.74430	2.85806	.13345	.00009	.00000	2.99150

TABLE: 35 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL (10/90 BY WT)

PRESSURE =3.0: TEMPERATURE =1600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.61248	.71378	.06728	.19824	2.32626
.50	.78722	2.10568	.84251	.01092	.00000	2.94820
1.00	1.57443	2.26432	.71496	.00315	.00000	2.97928
1.50	2.36164	2.36778	.61862	.00137	.00000	2.98639
2.00	3.14886	2.44396	.54505	.00071	.00000	2.98902
2.50	3.93608	2.50301	.48720	.00041	.00000	2.99022
3.00	4.72329	2.55031	.44053	.00026	.00000	2.99084
3.50	5.51050	2.58912	.40207	.00017	.00000	2.99119
4.00	6.29772	2.62157	.36983	.00012	.00000	2.99140
5.00	7.87215	2.67284	.31878	.00006	.00000	2.99162
6.00	9.44658	2.71156	.28017	.00003	.00000	2.99173
7.00	11.02101	2.74185	.24993	.00002	.00000	2.99178
8.00	12.59544	2.76621	.22560	.00001	.00000	2.99181
9.00	14.16987	2.78624	.20559	.00001	.00000	2.99183
10.00	15.74430	2.80299	.18885	.00001	.00000	2.99184

TABLE: 36 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE = 400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.00468	.00000	.55477	.38406	.00468
.50	.78722	.00643	.00000	.66070	.17132	.00644
1.00	1.57443	.00858	.00001	.74582	.00000	.00858
1.50	2.36164	.01154	.00001	.74508	.00000	.01154
2.00	3.14886	.01447	.00000	.74435	.00000	.01447
2.50	3.93608	.01738	.00000	.74362	.00000	.01739
3.00	4.72329	.02029	.00000	.74289	.00000	.02030
3.50	5.51050	.02319	.00000	.74217	.00000	.02319
4.00	6.29772	.02608	.00000	.74145	.00000	.02608
5.00	7.87215	.03183	.00000	.74001	.00000	.03184
6.00	9.44658	.03757	.00000	.73857	.00000	.03757
7.00	11.02101	.04328	.00000	.73715	.00000	.04328
8.00	12.59544	.04897	.00000	.73572	.00000	.04897
9.00	14.16987	.05463	.00000	.73431	.00000	.05464
10.00	15.74430	.06028	.00000	.73290	.00000	.06028

TABLE: 37 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE = 600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.03314	.00015	.57086	.33758	.03329
.50	.78722	.04643	.00029	.70590	.06077	.04672
1.00	1.57443	.06798	.00030	.73090	.00000	.06828
1.50	2.36164	.09092	.00029	.72516	.00000	.09121
2.00	3.14886	.11340	.00028	.71955	.00000	.11368
2.50	3.93608	.13550	.00028	.71402	.00000	.13578
3.00	4.72329	.15728	.00028	.70857	.00000	.15757
3.50	5.51050	.17877	.00028	.70320	.00000	.17906
4.00	6.29772	.19999	.00028	.69790	.00000	.20028
5.00	7.87215	.24167	.00028	.68748	.00000	.24196
6.00	9.44658	.28242	.00029	.67729	.00000	.28271
7.00	11.02101	.32231	.00029	.66732	.00000	.32260
8.00	12.59544	.36139	.00029	.65755	.00000	.36168
9.00	14.16987	.39972	.00030	.64796	.00000	.40002
10.00	15.74430	.43734	.00030	.63856	.00000	.43764

TABLE: 38 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE = 800.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.12986	.00279	.54976	.33009	.13266
.50	.78722	.18333	.00548	.69273	.01606	.18881
1.00	1.57443	.27416	.00528	.67811	.00000	.27944
1.50	2.36164	.36121	.00520	.65636	.00000	.36641
2.00	3.14886	.44407	.00522	.63564	.00000	.44929
2.50	3.93608	.52349	.00527	.61578	.00000	.52876
3.00	4.72329	.59992	.00533	.59665	.00000	.60525
3.50	5.51050	.67367	.00541	.57820	.00000	.67907
4.00	6.29772	.74498	.00548	.56035	.00000	.75046
5.00	7.87215	.88100	.00563	.52631	.00000	.88663
6.00	9.44658	1.00914	.00576	.49424	.00000	1.01489
7.00	11.02101	1.13019	.00587	.46395	.00000	1.13606
8.00	12.59544	1.24477	.00598	.43528	.00000	1.25075
9.00	14.16987	1.35337	.00606	.40811	.00000	1.35943
10.00	15.74430	1.45635	.00613	.38235	.00000	1.46248

TABLE: 39 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE =1000.OF

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.34792	.02429	.47398	.36187	.37220
.50	.78722	.49176	.04670	.60243	.02184	.53846
1.00	1.57443	.71514	.04684	.55747	.00000	.76198
1.50	2.36164	.91954	.04699	.50633	.00000	.96653
2.00	3.14886	1.10530	.04745	.45978	.00000	1.15275
2.50	3.93608	1.27556	.04790	.41710	.00000	1.32346
3.00	4.72329	1.43224	.04824	.37785	.00000	1.48048
3.50	5.51050	1.57665	.04842	.34170	.00000	1.62507
4.00	6.29772	1.70979	.04844	.30841	.00000	1.75823
5.00	7.87215	1.94515	.04803	.24967	.00000	1.99319
6.00	9.44658	2.14320	.04708	.20039	.00000	2.19029
7.00	11.02101	2.30794	.04571	.15956	.00000	2.35364
8.00	12.59544	2.44311	.04401	.12619	.00000	2.48712
9.00	14.16987	2.55249	.04210	.09932	.00000	2.59460
10.00	15.74430	2.63988	.04009	.07798	.00000	2.67996

TABLE: 40 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE =1200.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	.70526	.12298	.34915	.38351	.82824
.50	.78722	1.00100	.23008	.44020	.00000	1.23108
1.00	1.57443	1.39588	.22695	.34226	.00000	1.62283
1.50	2.36164	1.71273	.22280	.26408	.00000	1.93553
2.00	3.14886	1.96825	.21613	.20187	.00000	2.18438
2.50	3.93608	2.17270	.20728	.15297	.00000	2.37998
3.00	4.72329	2.33430	.19692	.11516	.00000	2.53122
3.50	5.51050	2.46042	.18577	.08642	.00000	2.64620
4.00	6.29772	2.55791	.17445	.06487	.00000	2.73237
5.00	7.87215	2.69054	.15296	.03709	.00000	2.84349
6.00	9.44658	2.76978	.13432	.02194	.00000	2.90410
7.00	11.02101	2.81892	.11882	.01353	.00000	2.93774
8.00	12.59544	2.85099	.10608	.00870	.00000	2.95707
9.00	14.16987	2.87305	.09558	.00581	.00000	2.96863
10.00	15.74430	2.88896	.08686	.00401	.00000	2.97582

TABLE: 41 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE =1400.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.13366	.37096	.21453	.31456	1.50462
.50	.78722	1.65329	.57235	.19156	.00000	2.22564
1.00	1.57443	2.05839	.53632	.09929	.00000	2.59471
1.50	2.36164	2.29575	.48230	.05345	.00000	2.77805
2.00	3.14886	2.44198	.42893	.03024	.00000	2.87091
2.50	3.93608	2.53766	.38207	.01803	.00000	2.91973
3.00	4.72329	2.60414	.34252	.01130	.00000	2.94666
3.50	5.51050	2.65282	.30944	.00740	.00000	2.96227
4.00	6.29772	2.69003	.28170	.00503	.00000	2.97174
5.00	7.87215	2.74338	.23827	.00255	.00000	2.98165
6.00	9.44658	2.78004	.20612	.00143	.00000	2.98616
7.00	11.02101	2.80695	.18148	.00086	.00000	2.98844
8.00	12.59544	2.82764	.16205	.00055	.00000	2.98968
9.00	14.16987	2.84407	.14634	.00036	.00000	2.99041
10.00	15.74430	2.85746	.13340	.00025	.00000	2.99086

TABLE: 42 SURVEY THE STEAM REFORMING OF INDOLINE AND METHANOL(10/90 BY WT)

PRESSURE =5.0: TEMPERATURE =1600.0F

YIELD TO CARBON RATIO

(H2O/F)W	(H2O/C)M	(H2/C)M	(CO/C)M	(CH4/C)M	C(S)/C	(H2+CO)/C
.00	.00000	1.51441	.66476	.10195	.20246	2.17917
.50	.78722	2.05989	.82219	.02745	.00000	2.88207
1.00	1.57443	2.24899	.70890	.00849	.00000	2.95789
1.50	2.36164	2.36072	.61613	.00375	.00000	2.97685
2.00	3.14886	2.44015	.54385	.00196	.00000	2.98401
2.50	3.93608	2.50074	.48656	.00114	.00000	2.98730
3.00	4.72329	2.54886	.44016	.00071	.00000	2.98902
3.50	5.51050	2.58815	.40184	.00047	.00000	2.98999
4.00	6.29772	2.62089	.36968	.00032	.00000	2.99058
5.00	7.87215	2.67248	.31871	.00017	.00000	2.99120
6.00	9.44658	2.71135	.28013	.00010	.00000	2.99149
7.00	11.02101	2.74172	.24991	.00006	.00000	2.99163
8.00	12.59544	2.76613	.22558	.00004	.00000	2.99171
9.00	14.16987	2.78618	.20558	.00003	.00000	2.99177
10.00	15.74430	2.80294	.18885	.00002	.00000	2.99179

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental study was made on the effects of gasoline contamination of methanol relative to steam reforming of the mixture.

At the conventional steam reforming temperature of 350-400°F soot was produced with a 90/10 mixture of methanol and gasoline (by weight). A parametric study was conducted to evaluate the effects of higher temperature and higher steam to carbon ratio with four different catalysts.

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Soot-free operation was obtained with Girdler catalyst T-2107 at an operating temperature of 750°F at a steam to (total) carbon ratio of 3.8. Essentially all the gasoline is converted into light gaseous hydrocarbons, primarily methane. A trace of light-yellow oil droplets could be detected in the cooled product gas condensate.

A 100 hour test showed no deterioration of the T-2107 catalyst activity under the above conditions.